The Project Method of Teaching

HAND FIRING OF LOCOMOTIVES

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HAND FIRING OF LOCOMOTIVES

FIRING COALS OF THE EASTERN STATES

INTRODUCTION

1. Purpose of the Instruction.—Before a man can be an efficient locomotive fireman, there are many things that he must learn. Some men acquire this knowledge during years of firing service, learning from the hard knocks of experience. Others learn through the quicker and easier method of studying the experience of others as set forth in written instructions. The purpose of this instruction is to furnish practical information to locomotive firemen on all necessary subjects pertaining to the firing of the coals of the Eastern States.

2. Importance of a Knowledge of Coal.—One of the first essentials of an efficient fireman is a knowledge of the different kinds of coal. There are more than fifty varieties of coal in the country and every variety is burned in locomotives. Some of these coals are good steam coals, others are only fairly good, and still others are burned in a locomotive firebox only with the greatest difficulty.

As there are so many grades and varieties of coals, it is easy to understand that the methods of firing employed must be suitable to the grade and variety of the coal used, and the fireman must know what method to employ in each case. Furthermore, the ash-pan, grates, firebox, and draft adjustment must be suitable to the coal being burned, and the fireman should know whether the conditions are right. If an engine is designed to

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burn a certain type and grade of coal, better results will be obtained with that grade than with either a better or a poorer grade. For that reason, where conditions will permit, each coaling station should be continuously supplied with the same grade and type of coal, and the locomotives should be properly equipped and drafted to burn it. Under conditions where many grades of coal are supplied and must be burned in the same firebox, the fireman must learn to fire the different grades so as to obtain the best results with each.

COALS AND THEIR COMBUSTION

3. A study of the coals of the Eastern States shows that they consist of high-rank bituminous, semibituminous, semianthracite, and anthracite. Bituminous coal may be either a coking coal or a free-burning coal.

Coals that coke vary widely in coking properties. Those with the greatest tendency to coke swell up in burning, become pasty, and fuse into a mass of porous coke. This forms a protective covering over the surface of the fire, restricts the draft through the fire, and so cuts down the steaming capacity of the boiler. To offset this, the coke covering must be broken up from time to time with a slash bar, so that air can pass through the fire readily.

Coals that do not have a strong tendency to coke may become partly pasty but retain their form to a considerable extent unless disturbed. With some coals, if the rake is used on the fire, or, in some cases, if the grates are shaken roughly, the coal will run together and fuse into a porous coke that will cause considerable trouble.

Some coals have no tendency to coke. Such coals do not swell, soften, or fuse, but burn away gradually, becoming smaller and smaller until only the ash finally remains. Such coals are called free-burning to distinguish them from the coking coals. They may be raked freely without causing trouble unless in the process some of the ash is raised up into the hot zone of the fire, where it will melt and clinker.

4. Gas Coals.—In locomotive service, the bituminous coals are commonly known as gas coals, owing to the fact that about one-third of the weight of the coal is converted into gas during the process of burning. This gas is very hard to burn economically. If the firebox and draft appliances are not designed and adjusted to burn it, or if the firing is not done properly, a great waste of fuel will occur and clouds of black smoke may be produced. The other two-thirds of the coal consists of fixed carbon. This is the part that forms coke, which burns without smoke, like the coke of commerce. It burns at a bright red heat, without flame, and remains incandescent as long as burning continues, the heat produced by the combustion being sufficient to maintain incandescence. To obtain smokeless combustion, therefore, the gaseous part of the coal must be burned completely. It is comparatively easy to burn smokelessly any coal in which the gaseous matter does not exceed one-fifth of the weight of the coal.

5. Best Steam Coals.—Coals containing about one-fifth gaseous content and four-fifths fixed carbon give the best results for steam purposes. Those with a greater gas content have a lower heating value and give trouble from smoke, unless conditions for smokeless combustion are just right. Those with less than one-fifth gaseous content also have a smaller heating value, and are harder to ignite; but they burn without smoke even under rather unfavorable conditions.

6. Gases in the Coal.—The gases in the coal are driven off while the coal is being heated to red heat and are burned before the fixed carbon begins to burn, this action requiring from one-half minute to two minutes, depending on the rate of burning and the consequent firebox temperature. Where bituminous coal from the Eastern States is being burned, this means that one-third the weight of coal that is put in at a fire is burned within two minutes after firing. If a heavy fire of, say, nine scoops holding 15 pounds each were to be put in at a fire $(9 \times 15) \div 3 = 45$ pounds of gaseous matter would be burned within two minutes, which is 22½ pounds per minute. As about 300 cubic feet of air is required to burn a pound of the gas, $300 \times 22\frac{1}{2} = 6{,}750$ cubic feet of air, or the capacity of about three ordinary box cars, would have to pass through the firebox per minute merely to burn the gas of the nine scoops of coal. The coke of the coal burns in the fire bed with the air that comes through the fire, but the gas burns in the firebox space above the fire bed, and the air necessary to burn it must be supplied at that point. If the air is not supplied the gases cannot burn, but will simply be distilled from the coal by the heat of the fire and pass out of the stack unburned.

7. Coal Loss Through Unburned Gases.—When burning the high-volatile coals of the Eastern States, a very serious loss of fuel may occur through the escape of unburned gases unless the fireman knows how to prevent it. In burning, 1 pound of fixed carbon evolves 14,650 heat units, whereas 1 pound of the coal gases evolves 23,500 heat units. In a high-volatile, high-grade coal composed of two-thirds fixed carbon and one-third gaseous content, the two-thirds pound of fixed carbon would evolve 9,766 heat units and the one-third pound of gases would evolve 9,669 heat units. In other words, the one-third pound of the gases actually represents one-half of the heat value of the pound of coal. With such a coal, if a fireman allows his fire to get into a condition such that only half of the gases escape unburned, he would have the same waste of coal as if he burned all the gases but threw every fourth shovel of coal off the tender. With a high-volatile coal, it is an easy matter to waste a large quantity of fuel through unburned gases if there is insufficient draft or firebox volume, or if the fire is allowed to become dirty or too thick, or holes or banks are allowed to form. A much larger firebox volume is needed to burn a high-volatile coal without smoke than to burn a low-volatile or smokeless coal, and much more skilful manipulation of the fire is necessary.

8. Smoke-Forming Constituents of Coal.—In the manufacture of illuminating gas, a high-volatile coking coal is placed in an air-tight retort and heated until all the volatile is driven off. This process results in four products: coke, gas, tar, and sulphate of ammonia.

The coke is the fixed carbon and ash of the coal, which are left after the volatile is driven off through the heating of the coal. It amounts to from 65 to 75 per cent. of the weight of the coal, which is 1,300 to 1,500 pounds per ton of 2,000 pounds.

The gas obtained averages about 9,000 to 10,000 cubic feet per ton of coal coked.

The tar averages from 4 to 6.5 per cent., which is from 80 to 130 pounds per ton of coal.

From a ton of coal about 20 to 25 gallons of watery liquor is obtained, from which 1 to 1.5 per cent. (20 to 30 pounds) of sulphate of ammonia is obtained.

9. High-volatile coal in burning separates into four parts—coke, gas, tar, and ammonia liquor—the first three of which must be taken into account by the locomotive fireman. The fixed carbon, which may be coke, forms the fire bed, and there must always be a sufficient depth of it carried to prevent the draft from disrupting the fire bed and forming holes. Otherwise, the fixed carbon does not cause serious trouble, as it does not form smoke in burning, but lies quietly on the grates until it is completely consumed. If the fixed carbon cakes over the bed of the fire and forms a crust that prevents the free passage of air through the fire bed, it must be broken up periodically with the slash bar so as to allow a free passage for the air, otherwise it will be impossible to keep up the steam pressure. In breaking this crust, care must be taken not to raise the ash up into the hot zone of the fire, as it will fuse and form a clinker that will produce trouble. The fire bed must not be penetrated with the slash bar farther than is necessary to break the crust.

10. Quantity of Gas Given Off.—The quantity of gas given off by a coal may vary from 5,000 cubic feet per ton in a low-volatile coal to 10,000 cubic feet per ton in a high-volatile coal. If the firebox volume, the air passages through the ashpan and the grates, and the amount of draft are sufficient, and the draft is properly adjusted for burning the proportion of gas produced by the coal, there should be no difficulty in burning the gaseous portion of the coal smokelessly, provided the firebox is equipped with a brick arch. If smoke occurs at heavy rates of firing, it may be reduced by leaving the fire-door on the latch for a short period after each fire, so as to admit above the fire the air necessary to burn the gases while they are driven off in heaviest volume.

11. Tar Distilled From the Coal.—The tar distilled from the coal consists of about 50 per cent. of pitch and 50 per cent. of hydrocarbon oils and liquid paraffins. A coal rich in tarry vapors is a most persistent smoke maker, as the tar constitutes the worst smoke-producing constituent of the coal. The power of tarry vapors to make a dense black smoke will be readily understood if a small piece of tar is thrown on a fire and the quantity and color of the vapor that arises from it are noted. If the firebox temperature is high enough, any tar that escapes burning is decomposed into soot and fixed gases. The soot makes dense clouds of smoke, while the gases that escape unburned are a source of fuel waste.

12. Tendency of Coal to Produce Smoke.—The tendency of a coal to produce smoke depends on both the relative total quantity of volatile matter and on the temperature at which the smoke-producing part of the volatile matter is driven off. For example, Illinois and West Virginia Pocahontas coal contain practically the same amount of smoke-producing volatile matter. The Illinois coal gives off the major portion of its smoke-producing volatile at a low temperature (between 900° F. and 1,100° F.), and for that reason is a very hard coal to burn without smoke; the Pocahontas coal gives off the major portion of its smoke-producing volatile between 1,200° F. and 1,500° F., a temperature at which it is burned smokelessly with but little effort. Connellsville, Pennsylvania, coal gives off its major portion of smoke-producing volatile between 1,100° F. and 1,500° F., but as it contains a much greater proportion of smoke-forming volatile it must be burned with great care to prevent dense black smoke.

13. Rate of Distillation of Volatile.—Experiments have shown that the quantity and quality of the volatile distilled from a coal depends on the rate at which the coal is heated and the volatile driven off. With a slow rate of heating, the volatile is smaller in quantity and has a higher percentage of gas and a smaller amount of tarry matter. With a rapid rate of heating, a larger amount of volatile is obtained and a much larger proportion of this is in the form of tarry vapors and of hydrocarbon gases, which are hard to burn without smoke. For that reason, it is much harder to burn a coal without smoke at high rates of combustion than at low rates of combustion if the coal contains heavy smoke-producing volatile matter. Such a coal must have ample draft and ample air spaces in ash-pan and grates, the fire must be clean and as light as can be carried for the work the engine is doing, and there must be no leaks in the firebox or at the front end. At high rates of burning, smokeless combustion will be helped greatly by swinging the fire-door or leaving it on the latch for a short time after each fire. The fire-door must be swung shut after each scoop, so as to maintain a sufficiently high firebox temperature to insure smokeless combustion.

14. Smokeless Coals.—Coals, such as the semianthracite and semibituminous coals, that have not more than 20 per cent. of volatile matter are usually known as smokeless coals, because they can be burned at a much higher rate than the bituminous coals without producing black smoke. The reason for this is twofold: first, they have a smaller amount of volatile matter, and second, most of the tarry matter has been driven off through the longer period of pressure to which they were subjected. On the other hand, they are more friable and are not so well suited for transportation and repeated handling as the bituminous coals, especially the central bituminous coals of Illinois, etc., so they carry a higher percentage of slack coal, which must be taken care of by the fireman in order to avoid a large fuel loss.

15. Slack Coal.—Probably the worst fuel loss that a locomotive fireman has to contend with is that which occurs through the escape of unburned fine coal. Where the percentage of fine slack coal is very high, this loss may amount to one-quarter or even one-third of the coal fired. As a scoop of coal is being fired, the draft picks up the fine coal and shoots it through the tubes and out of the stack, in many cases even before it has been heated sufficiently to drive off the volatile gases. The harder the engine is working the stronger will be the exhaust and draft and the greater will be the fine-coal loss. That is one reason why the fuel record of a man in heavy freight service suffers when compared with the record of a man in light freight service of moderate schedule speed. Not only is the fine coal wasted, but the sparks and live cinders thrown out along the right of way are responsible for many fires during dry seasons of the year.

16. Reducing Slack-Coal Loss.—The best method of reducing the loss through unburned fine coal is to wet the coal until the fine particles stick together while being fired. This can be done only by thoroughly drenching the coal at least a half hour before leaving time, so that the surplus water will have time to drain off. A *light* wetting will not prevent the loss of the fine coal and will add to the fuel loss, because the water must be evaporated and heated to the stack temperature at the expense of the heat of the firebox. In case the coal is sprinkled to keep down the dust in the cab, only just enough water to serve the purpose should be used, to reduce the loss through evaporation of the water.

17. Ash From Coal.—The analyses of coals of the Eastern States show that the ash may vary from 2 to 15 per cent. of the weight of coal. A fireman firing a coal with 15 per cent. of ash would fire 300 pounds of ash and 1,700 pounds of coal for each ton of coal used; with a coal having only 2 per cent. of ash he would fire only 40 pounds of ash and 1,960 pounds of coal. Furthermore, the extra 260 pounds of ash in the high-ash coal would clog the fire and probably clinker, and would interfere greatly with the proper burning of the coal. It certainly would cut down both the efficiency and the capacity of the firebox, and would tend greatly to produce smoke.

18. Foreign Impurities.—From the fireman's viewpoint the ash of a coal includes not only the inherent ash which is a definite part of the composition of the coal but also the impurities that become mixed with the coal during the process of mining and in transportation and after handling. The impurities foreign to the coal are the real trouble-makers. The inherent ash of a coal will not cause trouble from clinker if the fire is properly manipulated and the ash is not raised up into the hot zone of the fire. The foreign impurities, on the other hand, are sure to cause trouble.

The foreign impurities may consist of: iron pyrite, which occurs in some beds of coal in balls, bands, and lenses and in other beds in veinlets or as small particles and usually is a trouble-maker on account of the tendency of its iron to form clinker; slate, shale, and sandstone from the roof of the mine; slate, shale, and sulphur balls sandwiched in between the coal strata; clay from the floor of the mine; and pieces of iron, rock, and earth that are picked up en route or in the subsequent handling of the coal.

19. The foreign impurities are very apt to give trouble through clinkering. If they do not fuse they settle down onto the grate and as the run proceeds gradually form a screen on top of the grate that shuts off a large part of the grate air space and so restricts combustion. If the fireman does not know the cause of the trouble he will probably fire more heavily than usual, with the result that the thickness of the fire bed will be increased and the steam production decreased.

A great deal of worry and hard labor will be avoided if the fireman will watch every shovel of coal fired for pieces of rock, slate, and other impurities. These should be picked out of the coal and placed in a pile at one side near the gangway where they can be thrown off at some point where there is no danger of hurting persons who might possibly be along the right of way.

20. Hard Clinker.—The formation of hard clinker in a locomotive firebox is one of the chief causes of a fireman's troubles. Where clinker does not form, it is a comparatively easy matter to carry a light, level, clean fire that is easy on the coal pile and makes steam freely. When clinkers form, the fire becomes dirty, grows thick, burns unevenly, smokes, and steam pressure is maintained with the greatest of difficulty. Since the hard clinker, which is the form ordinarily met with, is formed generally by the melting of some foreign impurity in the coal, the way to avoid the clinker is to watch the coal for impurities and pick them out before firing the coal. The work required to do this is as nothing compared to the work and worry caused by throwing the impurities on the fire with the coal.

Hard clinker is sometimes formed by inserting the slash bar too deeply in the fire and raising some of the ash into the hot zone of the fire, where it melts and in cooling cements a lot of coal and ash together into a big clinker. The way to avoid this is to use the slash bar as little as possible, and then with care.

The appearance of the fire indicates when a clinker is forming. When a spot in the fire begins to grow darker in color than the rest of the fire and it is not due to a bank, it indicates that the air is restricted through that spot, probably due to the formation of a clinker. As soon as this is noticed the clinker should be broken up by a careful operation of the grates. The time to do this is when the clinker first forms. If it cannot be broken up by shaking the grates, it should be raised to the surface of the fire and removed at the first opportunity.

21. Soft Clinker.—Soft clinker is a slag formed by the chemical combination of the constituents of the ash at firebox temperature. To bring about this chemical combination, sufficient heat must be supplied to cause fusion. When a soft clinker first forms the appearance of the fire is the same as if a hard clinker had formed, but the soft clinker grows steadily in size until finally it spreads over the whole grate area. Inspection will show that the clinker is in a fluid condition underneath the crust. The fluid portion penetrates through the lower ash and often hangs like icicles from the grate bars.

Fortunately all ash does not contain the right constituents for combining chemically to form a slag at firebox temperatures. Also, the temperature of fusion usually is higher than the temperature to which the ash is subjected. It should always be borne in mind, however, that the temperature may be near slagging temperature and anything that may increase it only slightly may cause the ash to start slagging, and once this is started, it is practically impossible to stop it. The only way to remedy the trouble is to pull the fire, clean the firebox *and the grate,* and start a new fire.

22. Anything that increases the ash-pan temperature has a tendency to cause the formation of soft clinker, and anything that tends to reduce that temperature tends to prevent the formation of clinker. Therefore, as a precautionary measure against the formation of clinker, the ash-pan, which should have ample air openings, should be kept clean and after the grates are shaken, when weather conditions will permit, the hot ashes should be cooled by spray piped from the injector overflow pipes. The grates should not be shaken hard enough to shake burning coal into the ash-pan.

23. Mixing Coals.—Many coals may be mixed and burned without causing trouble from clinker. On the other hand, two coals, neither of which clinkers in burning, may cause considerable trouble from clinker if mixed and burned together, or if burned in the wrong order. For example, if anthracite or semianthracite is fired on a fire bed of bituminous coal, the result is almost sure to be disastrous, whereas bituminous coal can be fired on a fire bed of anthracite without the least trouble. It is well, therefore, for a fireman to know whether the coals at the two ends of a division can be burned together without causing trouble.

CONDITIONS FOR ECONOMICAL COMBUSTION

24. Draft of Locomotives.—It is important that an engine have the proper draft for burning coal economically at the rate necessary to supply the maximum amount of steam. If the draft is not sufficient, the engine will not steam, especially when working hard. If the draft is not distributed evenly, the fire will not burn evenly. When the action of the draft on the fire is not what it should be, the fireman should report it, being careful to tell exactly what is wrong. It should be borne in mind that while the action of the draft on the fire is not right, the trouble may not be due to wrong adjustment of the draft appliances, so no readjustment should be made until the actual cause of the trouble is located. If the fire indicates too little draft the draft appliances may be properly adjusted to produce the necessary draft, but steam or air leaks into the front end, or an obstruction in the ash-pan, grates, tubes, front end, or the netting may be reducing the amount of air flowing through the fire. Of course, the draft can be increased by reducing the size of the nozzle or by bridging the nozzle, but that will simply increase the waste of fuel through increasing the back pressure in the cylinders. The proper procedure is to find the cause and remedy that without touching the draft appliances unless they are found to be at fault. The ash-pan openings may be partly closed or the pan may be too full of ashes. A large number of air openings in the grate may be filled up. Often 60 per cent. of the openings have been found entirely closed. A large number of the tubes may be plugged up or the netting may be choked. The fireman should determine wherein the trouble lies so that he can turn in a correct report.

25. Draft Restrictions.—If a number of the air spaces in the grate are stopped up the fire will burn both poorly and unevenly on account of a lack of air. If the ash-pan opening on one side becomes partly closed up and the total amount of ash-pan air opening is small, the fire will burn poorly on the side on which the ash-pan opening is partly closed.

A fireman should insist that the real cause of any trouble be located *before any change is made in the draft appliances.* Of course, the draft can be regulated to offset the effect of leaks or other defects, but this means burning more coal to keep up the steam supply and additional work for the fireman. On the other hand, if the real cause of the trouble is located and remedied, the extra coal and work can be saved.

26. Failure of Engine to Steam.—Failure of an engine to steam, after being fired in accordance with the best practice, can generally be laid to a condition or set of conditions that decrease the draft or flow of air through the fire.

This may be due to conditions over which the fireman may or may not have control. The dampers or ash-pan netting may not be open, or the ash-pan may be full of ashes. Conditions over which he has no control are leaky steam pipes or superheater units, wash-out plug leaking in front end, blocked flues or netting, air leaks into smokebox, exhaust nozzle loose and leaking, and exhaust-nozzle tip of the wrong size or out of line with the stack. There may not be sufficient opening through the grates, or bricks may have fallen out of the brick arch.

The symptom of a reduced draft through the fire is difficulty experienced in getting the fire to burn white, as it will have a more or less dull color. Leaking tubes apparently reduce the draft out of all proportion to the extent of the leak. This is due to the fact that when water is heated to form steam, it increases in volume about eighteen hundred times. The steam generated from a small leak in the tube-sheet then has an appreciable effect in decreasing the draft through the fire.

27. Scale and Soot.—The effect of scale and soot on the steaming qualities of an engine is very marked. The loss in heat transmission due to ordinary scale varying in thickness up to $\frac{1}{8}$ inch may amount to 10 or 12 per cent. This means that out of every ton of coal fired from 200 to 250 pounds is practically wasted. In other words, in doing work that ordinarily would require the fireman to fire nine tons of coal with tubes clean of scale, the scale would make him fire ten tons, and he would have a much harder struggle to maintain steam pressure. On some roads today it is the practice when a locomotive has been out of the shop for six or eight months to either reduce the nozzle tip or to bridge it in order to offset the bad effects of scale and leaks. A much better practice is to treat the water and so avoid the formation of scale.

Soot is formed whenever coal is burned, but the better the combustion, the less soot will be formed. When the condition of the fire or careless firing causes smoke, clouds of soot are formed that coats the heating surfaces and seriously retards the transfer of heat to the water. Soot is said to be five times as good a non-conductor of heat as asbestos. Of course, the scouring action of slack coal passing through the tubes tends in a measure to clean them of soot, but even at the best there is a considerable fuel loss through soot. The fireman should watch for soot and should see that the tubes are bored out and cleaned frequently, thereby saving himself much unnecessary labor.

28. Waste at Pop Valve.—With a free-steaming engine, it is often difficult to prevent a large waste of steam at the pop valve. For every minute the pop is blowing, 15 pounds of coal is wasted. If during a run the aggregate time of blowing equals 90 minutes, the coal wasted will amount to $90 \times 15 = 1{,}350$ pounds. The pop wastes a scoop of coal each minute, so that every time it "lets go" the fireman must bend his back and put in a scoop of coal. This aggregates ninety scoops for the 90 minutes the pop was blowing, so the engineman can save the fireman much labor by being careful to prevent the pop from blowing.

If the fireman knows the run, it should be a comparatively easy thing for him to plan each fire far enough ahead so that when a regular stop occurs the pop can readily be prevented from opening. In local passenger service, when stops are many and short and stations close together, there is added difficulty in preventing pop waste. Just before closing the throttle the engineer should put on the injector and the fireman should crack the blower. This should prevent the pop from opening; but if indications are that it will not, the fire-door should be put on the latch or swung open and shut just enough times to prevent the pop from opening. While the engine is using steam, the fire-door should never be left wide open to prevent the pop from blowing or to cause the pop to cease blowing, as the large volume of cold air that would flow in a continuous stream through the firebox and tubes would cause tube leakage.

29. Cooperation of Engineer and Fireman.—The engineer and fireman must work in harmony with each other if good results are to be obtained. When pulling out of stations, the injector should not be started until the fireman has the fire in good condition, and the steam pressure is increasing. Otherwise the fire will have to be crowded to hold up the steam pressure. When approaching shutting-off points, the fire can be allowed to burn down somewhat, and the water level at this time should not be so high as to prevent the injector from being used to keep the engine from popping. The engine should not be run first with a light throttle and then with a heavy throttle, nor should the cut-off be changed frequently, as working the throttle and reverse lever in this way makes it impossible for a fireman to carry a steady fire and an even steam pressure. The position of the throttle and lever should, as far as possible, be changed only when a change in grade makes it necessary.

DETAILS OF FIRING

30. Preparing Fire for Start.—It is of the greatest importance to have a good fire with which to start the trip. If the fire is not put in shape before starting, it will give the fireman all kinds of trouble. For that reason he should get around in sufficient time to have his fire in perfect shape before leaving time, as he thereby will save himself much worry and hard labor during the run.

On arriving at his engine he should see whether the fire has been well cleaned. If it has not, he should knock out any clinker or ash that remains. Next, he should close the fire-door and put on the blower long enough to start the fire burning brightly so that he can detect any dead spots in it. Sometimes the fire cleaners in spreading the live coals after cleaning the fire do not entirely cover the grates and fire green coal on the bare spots. With a coal that ignites freely this will not matter so much, as the green coal will gradually ignite and the fire will spread over the dead spot. However, if there is a dead spot with the low-volatile, harder-to-ignite coals like the semi-anthracite, it will cause so much trouble that it should be done away with before starting. The green coal should be pulled away from the dead spot, the grate covered with good live coals, the green coal spread over the live coals, and the blower applied just long enough to ignite the green coal thoroughly.

31. Building Up the Fire.—After the fire has been put in good condition all over the grate surface, fresh coal should be lightly spread over it, and, if necessary, the blower put on very lightly. If there is sufficient time in which to build up the fire without the blower, it should not be used. It has been found by experience that when the blower is used freely in building up a fire, more clinker is formed and the fire is not in as good condition as when it is built up under natural draft. After the fresh coal that was spread over the fire is at a cherry-red heat, begin to build up the fire by spreading fresh coal thinly, first over one half of the firebox, lengthwise, and then over the other half. The idea is to always have one half of the fire at a red heat or better, when fresh coal is put on the other half, so that sufficient heat will be assured to burn the gases as they are driven off from the fresh coal. This method of firing will very materially reduce the amount of smoke produced in building up the fire.

32. The fire should be built up to the required thickness for the service as gradually as time will permit. Each fire should consist of only one, two, or three shovelfuls at a time, each being spread lightly and evenly over half of the firebox surface. A charge of coal that has been put on the fire must not be covered with more fresh coal before it has attained a red heat. Below a fairly bright red heat the first charge has not had its volatile matter driven off, and the second fire will simply retard the distillation and will cause the fire to build up too rapidly with green coal. Then, when the fixed carbon of the coal begins to burn, the hot zone of the fire will be so thick and so hot that clinker will result.

33. It is of the greatest importance to have a good fire covering the entire grate surface before leaving time for the trip. The depth of the fire will depend on the size of the coal, the weight of the train, and whether the start will be on an up grade, a level, or a curve. In other words, if the engine will have to work hard to start the train the depth of the fire at starting time must be greater than if the train is easily started. The coal necessary to keep up the steam pressure and to keep the fire in shape while the train is being started should be thoroughly ignited, and burning brightly before starting.

34. Depth of Fire.—It is important to know the best depth of fire to carry under various conditions. Many firemen do not understand this, and are in the habit of carrying one depth of fire at all times unless the thickness of the fire builds up during the run. This is a mistake that causes the fireman much extra work and worry, besides lowering his standing in the fuel records. For light loads, a light fire should be carried, while a thicker fire should be carried for heavier loads. It should not be thicker, however, than is necessary to withstand the effects of the exhaust, as that thickness will give the greatest fuel efficiency and the least trouble in burning.

TABLE I

EFFICIENCY OF BOILER AND FIREBOX

Depth of Fire Inches	Amount of Load Carried			
	Half Load Per Cent. Efficiency	Three-Quarters Load Per Cent. Efficiency	Full Load Per Cent. Efficiency	One-Quarter Overload Per Cent. Efficiency
6	73.5	67.5	64.0	60.5
7	68.5	67.0	68.5	62.0
8	65.0	64.0	68.0	63.0
9	63.0	60.5	66.5	62.0
10	62.0	57.0	63.0	58.0

35. Fuel Loss Through Thick Fires.—The effect of the thickness of the fire on the efficiency of a certain boiler and firebox is shown in Table I. These results hold good only for the boiler from which the results were obtained. If a test for another locomotive were to be made, the best depths of fire would very probably be different from those given, *but whatever they were found to be, they would vary in a manner similar to these figures.* The results found in the tests are presented merely to emphasize the fact that a lighter fire will give better results at light loads, whereas a heavier fire must be carried for heavy loads.

From the table it will be seen that in this test a 6-inch fire gave the best results for half and three-quarter loads, but that the efficiency was greatest at half load and dropped away rapidly as the load was increased. The 7-inch fire was not as efficient as the 6-inch fire for half load, but gave best results from three-quarters to full load. The 8-inch fire gave best results between full load and one and one-quarter load. The 9-inch fire did not give as good results as the 8-inch fire, while the 10-inch fire was considerably less efficient.

36. Suppose that the man firing for the test had the habit of always carrying a 10-inch fire. How much extra coal would he have had to fire on that account? For half load he would be wasting 11.5 per cent., or 230 pounds, out of every ton fired. For three-quarters load, he would waste 10.5 per cent., or 210 pounds per ton. At full load he would waste 5.5 per cent., or 110 pounds per ton. At one-quarter overload he would waste 5 per cent., or 100 pounds per ton fired. Burning this extra coal means more work in feeding the fire, and more work in keeping the fire at its best, because the more coal that is burned the more dirty the fire becomes. This extra labor and trouble can be avoided by carrying a depth of fire best suited to the load.

37. Preparation of Coal.—Most of the coal furnished for locomotive service is run of mine. Due to differences in the nature of the coal, in mining methods, methods of preparation, etc., there is a big difference in the make-up of the run of mine from different mines. Run of mine from a district where the coal is soft and friable has a high percentage of slack and a correspondingly low percentage of lump coal. Furthermore, the lumps crumble when exposed to the high temperature of the firebox, so they need not be broken so small as the lumps of the harder varieties. With a soft, friable coal, therefore, the loss of unburned slack must be prevented by thoroughly drenching the coal.

38. Most of the coal from the Eastern States is of the harder varieties, so that it has a lower percentage of slack and a higher percentage of lumps, many of which are too large to go through the fire-door. Now, fine coal and large lumps cannot be burned together, because the lumps burn slowly and tend to cause banks and clinkers; also, holes form around the lumps. A fireman will save worry and labor by breaking up large lumps to the size of medium-sized apples before shoveling them into the firebox.

39. Method of Firing.—The method of firing best adapted to the economical and smokeless burning of the bituminous coals of the Eastern States is indicated in Fig. 1. This shows that the fire is carried level throughout the grate, except

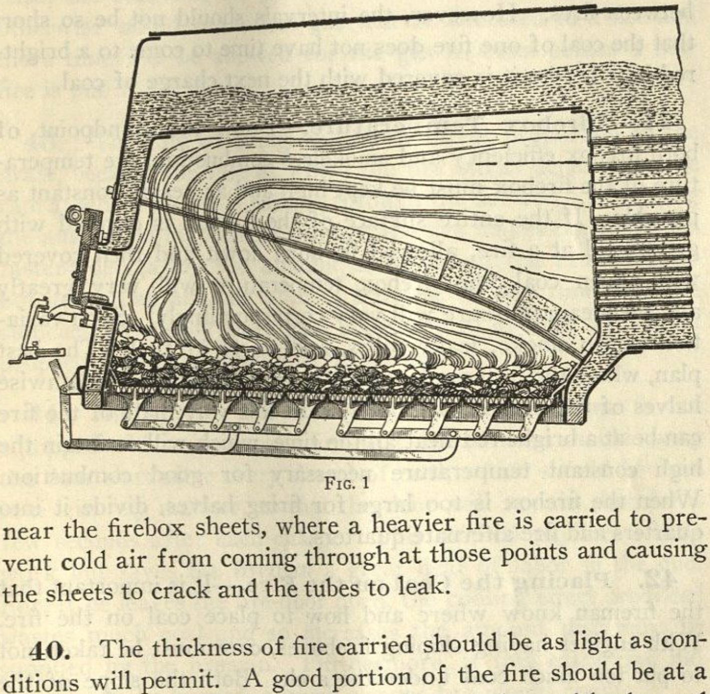

FIG. 1

near the firebox sheets, where a heavier fire is carried to prevent cold air from coming through at those points and causing the sheets to crack and the tubes to leak.

40. The thickness of fire carried should be as light as conditions will permit. A good portion of the fire should be at a white heat, the fire should be free from holes and banks, and the flame should be clear and non-smoky and short enough so as not to reach the tubes.

The thickness of the fire will increase if the ash continues to accumulate on the grate or if coal is fired faster than it is being burned. The fire should not be allowed to become thicker through the accumulation of ash, because that will surely lead to the troubles that go with a dirty fire. If the grate does not clear itself, it should be shaken very carefully as often as is necessary to prevent an accumulation of ash.

The coal put in at one fire should always be allowed to burn down before another fire is put in that part of the firebox. This is a cardinal principle of firing. If this is done, the fire will not build up in thickness. When the fire is to be built up in anticipation of heavy work, such as climbing a heavy grade, the coal is fired faster than it burns, by shortening the intervals between fires. However, the intervals should not be so short that the coal of one fire does not have time to come to a bright-red heat before it is covered with the next charge of coal.

41. Firebox Temperature.—From the standpoint of both firebox efficiency and smokeless combustion, the temperature of the firebox must be kept high and as nearly constant as possible. If the entire surface of the firebox is covered with green coal at a fire, allowed to burn down and then covered with green coal, the firebox temperature will vary greatly and the steam pressure will vary correspondingly. Such variations mean smoke, leaky tubes, and waste of fuel. The best plan, where the firebox is not too large, is to fire the lengthwise halves of the firebox alternately. In this way, half of the fire can be at a bright-red heat all the time, which will maintain the high constant temperature necessary for good combustion. When the firebox is too large for firing halves, divide it into quarters and fire alternate quarters.

42. Placing the Coal on the Fire.—It is important that the fireman know where and how to place coal on the fire. With engines having sloping fireboxes, care must be taken not to put too much coal under the arch. Both the slope of the firebox and the force of the draft tend to pull the coal ahead, and unless care is taken the fire will be banked up next to the tube-sheet, causing the forward section of the grates to become clinkered over and stuck. Most of the coal should be fired at the back end of the firebox and in the corners and along the sides. Fire only enough in the front end and in the middle of the firebox to prevent holes from forming.

The coal should be fired with only two or three scoops to the fire. It should be placed on the bright spots and never on the dark spots, as that has a tendency to form banks. The bright spots indicate the places where the fire has most nearly burned through. The intervals between fires should be lengthened or shortened according to the requirements. This procedure will make the fireman's work much lighter, as he will handle less coal and a steady steam pressure will be easily maintained. Also, the coal will be burned with much less smoke than it otherwise would be, as less gas will be liberated to a fire and more time will be allowed for the gas to burn before a new fire is put in.

43. The rate of firing will be in direct proportion to the draft, because the rate at which the fire burns depends on the rate at which the air is passing through the fire bed. Increasing the amount of air passing through the fire makes the coal burn faster; decreasing the amount slows down the rate of combustion. The amount of coal burning at any time must be sufficient to supply the steam necessary to operate the engine properly under the conditions prevailing.

44. Swinging the Fire-Door.—If the engine is not equipped with an automatic fire-door, the fireman should swing the door shut after every shovel of coal, which should be fired in a leisurely manner, so that the door will remain shut for a few seconds after each charge. This method requires a little work but saves the fireman a great deal of labor in the end. For, if he leaves the fire-door open, the cooling effect produced wastes much coal and so increases the amount that must be supplied by the fireman. Furthermore, if this extra coal did not have to be burned, a much cleaner fire would result.

45. Starting the Train.—By leaving time at the terminal station, there should be a good fire burning brightly all over the grates and of a suitable thickness for the work the engine will have to do in starting the train. Under some conditions it may be an advantage to put on the blower for a time just before starting, so as to have a good hot fire. If the train is a heavy one, the new fire may be torn up by the heavy exhausts; so the fire-door should be placed on the latch to reduce the draft above the fire and lessen the tearing effect. When the reverse lever is notched back, a fire should be put in to repair any damage done in starting, and the fire after that should be maintained to suit the work of the engine.

46. When to Put in a Fire.—The student fireman generally experiences difficulty in reading his fire—that is, he is not sure just when a new fire should be put in—the result being that he generally errs on the side of too much coal and crowds his fire, or adds fresh coal before the coal already in the firebox has been sufficiently burned. When this is done, the fire becomes too thick, the passage of air through it is obstructed, the steam pressure falls and there is, depending on the coal used, a tendency for clinkers to form. The time elapsing between firings will depend on the coal, draft, cut-off at which engine is working, etc., and can be determined either by the appearance of the fire or by the time interval between fires. The experienced fireman does not generally regulate his firing so much by the appearance of the fire as by the intervals of time his experience has taught him must elapse between fires under various conditions. In other words, he expects his fire to be in the proper condition for a fresh supply of coal after a certain time. The judgment necessary for a fireman to determine correctly the time between fires can only be acquired by experience, and in the meantime he must be guided to a great extent by the appearance of his fire. When the coal he has fired before his last fire has burned down to a dazzling white heat, this section of the grates is ready for another charge of coal. For example, if his last fire consisted of three scoops of coal on the right side of the firebox, when the left side has burned to a white heat, his next fire should be along that side. When putting in a fire the fireman should practice making a quick survey of the whole firebox and thus ascertain the kind of fire that is being carried.

47. Heavy Firing.—Heavy firing with bituminous coal makes both labor and trouble for the fireman. Some firemen habitually fire from eight to fifteen scoops to a fire when the engine is working hard. That is just the time the most skilful firing should be done; yet by heavy firing the fireman not only wastes a great deal of coal but also reduces his chances of maintaining the necessary steam pressure. A heavy charge lowers the firebox temperature and allows the gases to escape unburned. Cooling the firebox reduces the rate at which steam is generated, thereby reducing the maximum hauling capacity of the engine. On a long grade with a heavy freight, this might mean doubling the hill, whereas a properly fired locomotive would make the grade without doubling.

If a coal composed of one-third volatile matter were to be fired in charges of fifteen scoops, each holding 15 pounds of coal, each scoop would have 5 pounds of gas. The 15 scoops would contain $5\times15=75$ pounds of gas, and $75\times300=22{,}500$ cubic feet of air, or the contents of ten box cars, would be required to burn the gases without counting the air necessary for the burning of the fixed carbon. The draft appliances are not adjusted to admit such a supply of air, and so most of the gases escape unburned. The consequence is that the fireman gets no useful results from half the coal he is firing, and just at a time when he should be getting all the heat that the coal is capable of giving. Firing two or three scoops to a fire at frequent intervals would cut his labor in half, maintain a better steam pressure, and greatly reduce the trouble from dirty fires. Furthermore, it would prevent the big fluctuations of temperature that occur with heavy firing, thereby preventing trouble from tube leakage.

48. Firing Poor-Steaming Engines.—Under favorable conditions—that is, when the coal is of fair average quality and the engine is properly drafted—it is a comparatively easy matter to carry a good head of steam if the fireman keeps in mind the correct principles of firing. However, when the conditions are not favorable, due either to the fuel or to the engine, it is only by exercising good judgment that it is possible to have a successful trip. The fireman should not assume that conditions unfavorable to the free steaming of an engine should cause him to deviate from principles that his experience has taught him produce the best results, as it is only by the application of these principles that the greatest degree of heat can be obtained under any conditions, favorable or otherwise. He should, on the contrary, apply the principles of correct firing to the conditions under which he is working, and, even if the engine is not kept hot, be satisfied that the results derived from their application will be the best obtainable. For example, if steam leaks reduce the vacuum in the smokebox and therefore decrease the draft through the fire, special effort should be made to keep the fire clean and light, so as to facilitate as far as possible the passage of the reduced volume of air entering through the grates to the fire, and thus compensate for the reduction in the draft due to leaks. Care should also be taken under these conditions to fire more lightly than usual, as it is very easy to overcrowd the fire under any conditions that cut down the draft. The tendency, however, when an engine is not steaming freely, is to fire too much coal, which in a great number of cases merely aggravates the trouble. In the case of poor-steaming engines there should be closer cooperation between the engineer and fireman than is usually necessary when conditions are more favorable.

49. Filling Up of Firebox.—Trouble is sometimes experienced by the fire increasing in thickness rapidly even when the grates are shaken frequently. As it is practically impossible in certain classes of service to keep shaking the grates continually, steam failure and detention of the train result. There are two principal causes of filling up the firebox: an excess of ash or foreign matter in the coal, and incomplete burning of the coke. In the first case nothing can be done except to keep the fire as thin as possible by frequent shaking of the grates; but in the latter case the trouble can be avoided by changing the manner in which the coal is being fired.

Some classes of coal burn more slowly than others, and require more time for the gases to distill out, and less smoke is emitted at the stack. Fresh coal is frequently added before the coal already in the firebox has completely burned, causing the fire to become too heavy. Coal of this nature should be fired as light as possible, erring, if necessary, on the side of too little coal rather than too much, until the correct method of firing is found. An examination of the contents of the ash-pan will show whether the trouble is due to impurities in the coal or too heavy firing, as in the latter case a large amount of unburned coke will be found in the ashes.

50. Shaking the Grates.—How frequently the grates should be shaken depends on the style of grate, the amount of ash in the coal, and the amount of clinker-forming material in the ash. If the grate has the proper air openings for the coal being burned, and the air openings are not plugged up, and if the ash from the coal is fine and does not clinker, it is possible to go from terminal to terminal without shaking the grates. On the other hand, if the air openings are not right, or are filled up, or if the coal is high in ash and clinkers and contains rock and slate that are not picked out before firing, it will be impossible to get along without shaking the grates. The fireman, therefore, must judge as to whether or not it is necessary to shake the grate; however, he should bear in mind that it should never be shaken except when necessary, as fire trouble is apt to result.

If the appearance of the fire indicates that there is a restriction of the air passing through, the grates should be carefully shaken and the shaking should be repeated every time the appearance of the fire indicates the necessity. The time to shake the grates is when the throttle is closed or when the exhaust is very light. The object of shaking is to remove the dead ashes and clinker from the bottom of the fire, and the shaking should stop at the first indication of live fire dropping into the ash-pan, not only to save fuel but to prevent burning out the grates by live fire in the pan.

Care must be taken always to lock the grates in their level position; otherwise, the fingers on one side of the grate bars will project up into the fire and will probably be burned off, or clinker may get wedged between the fingers of adjacent grate bars and hold them open so that live fire can fall into the ash-pan.

51. Use and Abuse of Blower.—When the blower must be used, turn it on just as lightly as will do the work. If the blower is used too strongly and at the wrong time it will cause damage to the boiler. The most frequent abuse of the blower and the one that does the most damage to the boiler is using it too strongly with the fire-door wide open or when raking or cleaning the fire. In doing this work, the blower should be put on only just strong enough to prevent the gases from coming out the fire-door into the fireman's face. Turning the blower on harder than is necessary is pretty sure to cause leaky tubes.

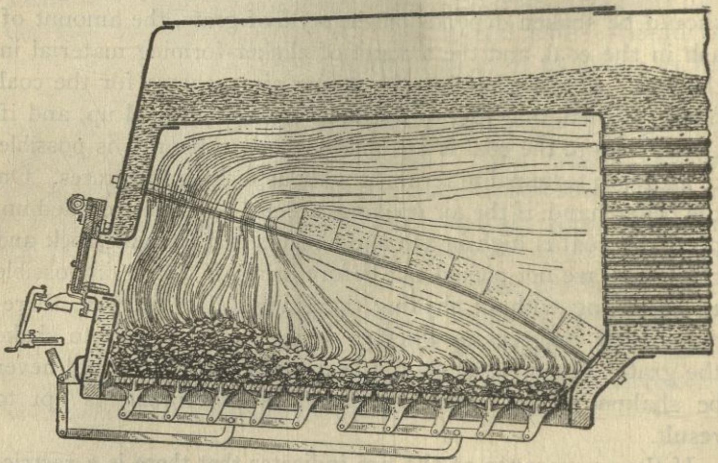

FIG. 2

52. Banks in the Fire.—The condition of the fire known as a bank is indicated in Fig. 2, and is brought about by the building up of the fire bed considerably above the level of the fire at one point, due to slow burning at that point. Anything that restricts the draft through the fire at any point in the firebox will cause the thickness of the fire at that point to build up and a bank to form. A clinker on the grates, or firing one scoop of coal upon another before the coal from the first scoop has had time to get red hot will form a bank. If the draft at one point in the firebox is very light and coal is fired at that point at the same rate as for the rest of the fire where the draft is normal, a bank will build up at the point of weak draft. A bank cuts down the amount of active grate area and makes the distribution of the draft uneven; therefore, it should be removed, if possible, or else coal should be fired around it so as to cause it to burn out. If it is not gotten rid of, it will start a bad clinker.

53. Holes in Fire.—When a hole is allowed to form in a fire, as in Fig. 3, it should be repaired at once. Never fill up a hole with green coal, as it will either remain a dead spot or develop a clinker, depending on the kind of coal being burned. Fill the hole with live coals by leveling the fire at that point, and then sprinkle fresh coal over the part leveled.

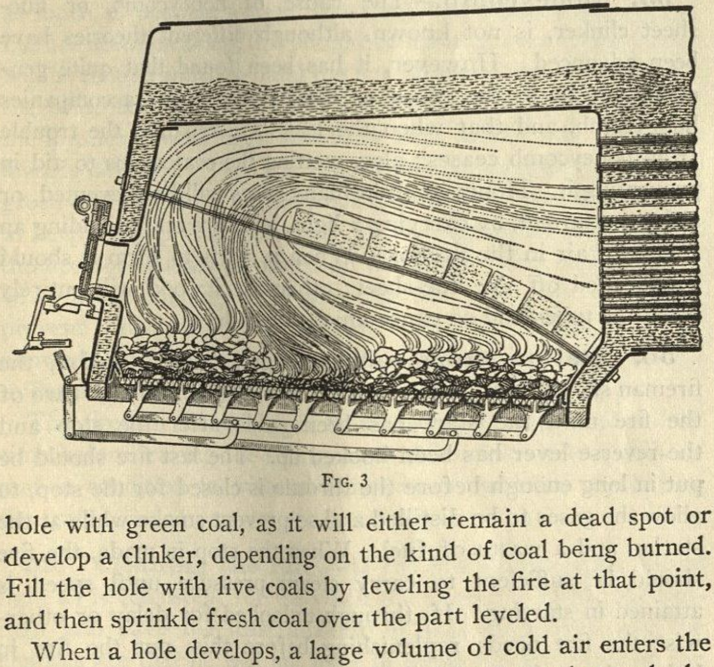

FIG. 3

When a hole develops, a large volume of cold air enters the firebox and passes to the tubes in a solid stream that cools the firebox and contracts the tubes and sheets, causing leaks. Also, so much air passes through the hole that the draft through the fire bed is greatly reduced. This still further lowers the rate of combustion and the firebox temperature, and results finally in cracked sheets and leaky tubes.

54. Clinkers in Fire.—Clinkers cause the worst troubles for the fireman; therefore, he should take all precautions to avoid them. In case they form, the first opportunity must be taken to get rid of them, which may be done by hooking them out, knocking them out, or by raising them to the surface of the fire where they may burn out and crumble. The work of removing a clinker must never be attempted while the engine is working, because in removing it there will be an inrush of cold air, which will cause injury to the firebox sheets and the tubes.

55. Honeycomb.—The cause of honeycomb, or flue-sheet clinker, is not known, although different theories have been advanced. However, it has been found that quite generally a leak in the tubes or the firebox sheets accompanies honeycomb, and that when the leaks are repaired the trouble from honeycomb ceases; also, wetting the coal seems to aid in preventing it. Honeycomb in many cases will be prevented, or at least retarded, by carrying a light, level fire and providing an excess of air in the firebox. When it starts to form it should be knocked off the flue-sheet; otherwise it soon will entirely block the tubes and so cause an engine failure.

56. Station Stops.—When approaching a station, the fireman should have sufficient coal in the firebox to take care of the fire until the start has been made after the stop and the reverse lever has been hooked up. The last fire should be put in long enough before the throttle is closed for the stop, to allow the gases to be distilled and so prevent smoke while at the station and a waste of fuel. When the stop is made, the fire should be sufficient to carry steam pressure until speed is attained in starting. If, through unlooked-for delay or otherwise the fire needs replenishing before this, put the fire in before the train starts. It is a poor practice to put in a fire while the exhaust is heavy, because the open fire-door will let such a large stream of cold air through the firebox and tubes as will cause leakage of the tubes and sheets.

57. Descending Grades.—In approaching a long down grade where the engine will drift with throttle closed, precautions must be observed to keep the pop from blowing. The fire should be burned down as low as possible without dropping the steam pressure. If there is danger that the pop may open after the throttle has been closed, enough coal should be sprinkled over the fire to prevent this. Also, if necessary, the fire-door may be left on the latch or swung back and forth to prevent popping. While the engine is on the descent is a good time to clean the fire if this is necessary.

58. Waiting on Sidings.—When approaching a siding where a long wait is expected, the fire should be burned down as much as possible without lowering the steam pressure. If the fire needs cleaning, this should be done at once so that there will be time in which to build the fire up into shape again before the train has to start. If the fire does not need cleaning, but the injector is working, it should be kept bright until the water level is obtained. Then the fire should be sprinkled over with green coal and if the engine has dampers they should be closed to keep the pop from blowing. If the engine has no dampers, the fire-door should be placed on the latch. The object should be to avoid popping by keeping the fire only high enough to prevent a drop in steam pressure. The fire should never be allowed to get so low as to lose steam pressure, as leaks are apt to develop.

The fireman should begin to prepare his fire in plenty of time before leaving the siding, so that he will have it built up and in condition to withstand the heavy exhausts of starting the train.

59. Cleaning the Fire.—If the fire is always carried as light as is consistent for the work the engine is doing, the fireman will have the least amount of coal to shovel, and the chances are that he will not have to clean the fire while on the road. If he does have to clean it, the work of cleaning it will be very much less than if a thick, heavy fire were carried. Heavy firing, either before or after leaving, increases the formation of clinkers and so reduces the time that a fire can go without cleaning. By carrying a light fire, therefore, and taking precautions against the formation of clinker, a fireman can save himself the hard, hot work of cleaning the fire during the run.

Where a train is a long time on the road and the fire becomes dirty and clinkered, it should be cleaned at the first opportunity. The fireman will be well repaid for this labor, as he will get better results with less work and coal, and will avoid leaky tubes.

If an opportunity is not presented during the run for thoroughly cleaning the fire, a small amount at a time should be cleaned as conditions permit. In this way it will often be possible to complete the trip, whereas without doing so a stop would have to be made to enable the fire to be cleaned.

60. Cleaning the Ash-Pan.—It is very important that the ashes be not allowed to accumulate in the ash-pan, and that no live fire be shaken into the pan and allowed to burn there. The temperature in the ash-pan rises rapidly as the pan fills with ashes, thereby greatly increasing the tendency of the ash to melt and form a clinker. If fire is allowed to burn in the ash-pan, not only will clinker form on the grates, but also the grates are very apt to be burned out. Some roads pipe the overflow pipes from the injectors into the ash-pans, so that after the grates have been shaken the injector primer can be started and water sent through the overflow pipe to put out any fire that may have been shaken into the pan.

Some roads equip the ash-pan with steam blowers for the purpose of cleaning. In some cases, one pipe in the center is used, while in other cases two pipes are used, one on each side of the center. The steam blower is not only useful in cleaning out the ashes, but also serves to clean the snow and ice from the pan in winter, thereby avoiding delays necessary to melt the snow and ice by means of a fire.

61. Terminal Stop.—On approaching a terminal station, the engineer should see that there is plenty of water in the boiler and that full steam pressure is carried. The fireman should have enough coal burning on the grates so the hostler will not be required to put in a fresh fire while the engine is in his charge. There should be a good bed of fire left for the fire cleaners, so that the fire can be cleaned properly.

The last fire put in by the fireman should be fired at a distance from the terminal sufficient to enable the gases to be distilled from the coal before the throttle is closed. The fire should be allowed to burn down so that there will be just the right amount of brightly burning coal for the purposes of the hostler when the train arrives at the station.

62. Summary of Firing Instructions.—The following is a brief summary of the instructions on the hand-firing of locomotives as given in the preceding pages; to obtain the results indicated in the following paragraphs it is assumed that the coal used is of fair average quality and does not require any special method of handling when being fired.

The fireman should be at the roundhouse in ample time to prepare his fire properly for the trip. He should ascertain that he has all the necessary tools used in firing on the engine before leaving the roundhouse and should examine the firebox to see if there are any leaks that would be a detriment to the fire or draft and cause engine to fail to steam. The smokebox door should be examined to see that it does not leak and that the nuts holding it closed are screwed up tight. He should ascertain if the grates can be worked, if the fire is free from clinkers, that the ash-pans are clean, and if the slides can be worked. He should also perform any other additional duties prescribed by the rules of the company.

63. The fire should be built up to the required thickness by adding two or three scoops of coal at a time, and putting the blower on lightly. In order to make a solid bed of fire and avoid the formation of clinkers, additional coal should not be added until the coal already in the firebox has been well burned. The final thickness of the fire will depend on conditions, such as the service the engine is in, the intensity of the draft, quality of the coal, etc., but should be sufficient to insure that the starting and pulling out of the train will not injure the fire when the engine is being worked at long cut-off. When building up the fire, the injector can be put on, if necessary, to prevent the engine from popping.

64. After the train has been started, the coal should be fired at regular intervals, closing the door between scoopfuls. Two or three scoopfuls of coal well scattered should be about the amount necessary to fire at one time. The fireman should aim to keep a level fire by scattering the coal, a bright fire, and a fire of uniform depth by frequent and light shaking of the grates. The fire carried should be as thin as conditions will permit. Banks, holes, and dead places in the fire, especially next the flue sheet, must be avoided. As a general rule, the tendency is for the fire to burn the heaviest in the four corners of the firebox, along the sides, and next the flue sheet. In this event the fire, instead of being level, should be thicker at these points.

65. Fresh coal should not be added until the fire has burned down to a white heat, if the conditions under which the engine is working permit. The steam gauge should be watched closely for indications of improper conditions in the firebox. When the steam pressure begins to fall under apparently favorable conditions, the fireman should examine his fire for banks, holes, or clinkers. The fireman should make a practice of noticing the condition of the fire during the time the door is open when putting in a fire, and should endeavor to carry a mental picture of his fire at all times. Shake the grates as lightly as possible and often enough to keep the fire clear of ashes and of the correct depth to secure the best results for the conditions under which engine is working. The frequency with which the grates should be shaken will depend on the amount of waste material in the fuel, but ashes should not be allowed to accumulate to such an extent as to render a heavy shaking of the grates necessary. The grates should not be opened up too wide at first, but should be partly opened and closed with short quick jerks. This tends to break up clinkers and avoid the possibility of their being caught in the grates and holding them open. With power grate shakers, if the grates are frequently moved with the limiting lock in position, it will be unnecessary to throw this lock out and open the grates fully.

66. Endeavor to carry as even a steam pressure as possible when the engine is working. This implies a more or less constant firebox temperature and reduces the tendency of the flues to leak. A high temperature can be maintained by keeping the fire bright, clean, and as thin as conditions will permit, the coal being fired light and often, and well scattered, the door being closed after each scoop.

Except when cleaning the fire, use the rake or hook only when necessary to break up the coke. If the coal is broken up small and fired lightly, very little coke will form and excessive use of the rake can be avoided.

To avoid smoke when shutting off for stations, put in the last fire far enough back so that it is burned down. Crack the blower when putting in a fire at stations, and avoid smoke by firing lightly and putting the fire-door on the smoke notch.

The fireman should learn the road over which he is firing and fire according to the grades. He should let the fire burn down for a meeting or passing point if they have to take the siding, and should know where to prepare for the bottom or summit of a hill, and also know how the engineer is going to work the engine at these places.

The deck and gangways of the engine should be kept clean and free from coal not only to prevent loss by falling off, but also to prevent accidents due to stepping on loose coal.

COMBUSTION

CHEMICAL ELEMENTS AND COMPOUNDS

GENERAL DEFINITIONS

67. Every body or mass of matter is either an element, a compound, or a mixture.

A **compound** is a substance formed by the chemical combination of two or more elements, and therefore can always be decomposed into separate substances. Water, for example, is a compound formed by the chemical combination of the gaseous elements, hydrogen and oxygen, and can be decomposed into these elements by passing a current of electricity through it. Any substance that can be decomposed into other substances is called a compound. Examples of compounds are wood, salt, lime, and the resultant gases of combustion.

68. Such substances as cannot be decomposed or broken up into separate substances by any known means are called **elements.** Silver, for example, is an element, and it is made up of but one substance. The innumerable compounds in the world are really made up of various combinations of a comparatively small number of elements. Some of the more common elements are oxygen, hydrogen, nitrogen, carbon, sulphur, iron, tin, lead, copper, zinc, gold, silver, nickel, and mercury. In the study of combustion, however, only the first six of these elements are of interest to the fireman and are the only ones that will be considered here. The elements are generally represented by *symbols,* which usually are the first letter of their names: thus, O stands for oxygen; H, for hydrogen; N, for nitrogen; and C, for carbon. A compound is expressed by combining the separate symbols of its elements; such a combination is called its *chemical formula.*

69. Atoms of elements combine to form molecules of elements and of compounds. An **atom** is defined by chemists as the least part of an elementary substance that can enter into or be expelled from a compound. Atoms of the same element are always of equal weight and volume, but they may differ in weight or volume, or in both, from atoms of other elements. They never exist in a separate state, but always combine with one or more atoms to form a molecule.

A **molecule** is the smallest quantity of an element or compound that is capable of a separate existence. It can be divided into its atoms only by a chemical process.

ELEMENTS

70. Oxygen.—Oxygen is one of the principal parts of the air, forming about one-fifth of it; the other four-fifths is nitrogen. These elements are not chemically combined, but are mixed together so that no chemical action is necessary to separate them. Should some element for which oxygen has a greater affinity, or liking for, be introduced into the mixture, the oxygen will leave the nitrogen and make a chemical combination with the other element. A chemical action takes place when oxygen forms a compound with any other element. If this element is a fuel, the chemical action is called combustion.

Combustion, or burning, cannot begin unless oxygen is present, nor can burning continue unless oxygen is available. Oxygen is therefore necessary to start combustion, and also to support it. During combustion, oxygen is the only element in the mixture known as the atmosphere that can be used in burning coal.

71. Hydrogen.—The element called hydrogen is the lightest substance known. It is a colorless, tasteless, odorless gas. In coal it exists in combination with carbon in the form of certain compounds called **hydrocarbons.** When the coal is thrown into the firebox, the heat to which it is subjected causes these hydrocarbon compounds to be driven off in the form of gases, the chief one being the gas known as **methane**, or **carbureted hydrogen.**

72. Nitrogen.—Four-fifths of the air is nitrogen, which is a tasteless, colorless, odorless gas that will not support life when breathed alone and that will not sustain combustion, or burning. It is well that so much of the air is nitrogen, for if the greater part of the air were oxygen, any fire, when once started, would burn so rapidly and fiercely that it could not be controlled. The large percentage of nitrogen acts as a sort of check on burning and so, to increase the rate of burning, it is necessary to create a draft, so as to circulate more air and so bring more oxygen in a given time to the point where the burning is going on.

73. Carbon.—The element that forms the larger part of coal is carbon. After the gases have been driven off from coal, the hard coke remaining consists largely of pure carbon. At ordinary temperatures it will not combine with any of the other elements to form chemical compounds. But if raised to a high temperature it will combine very readily with oxygen, for which it has a strong liking, or affinity.

THE COMPOUNDS, COAL AND WOOD

74. Coal.—Coal is a compound that consists of carbon, hydrogen, oxygen, nitrogen, sulphur, and iron in connection with other substances. The part of the coal that burns consists of the carbon, hydrogen, and sulphur; but as the sulphur is looked upon as an impurity in coal, and as its percentage is small when compared with the percentages of carbon and hydrogen, only the carbon and hydrogen will be considered as the parts of the coal that produce heat by their burning. The compounds of hydrogen and carbon in coal, or the hydrocarbons, are of a very complex nature and exist as gases, the principal one of which is methane, and also as a heavy tarry liquid. This tar, when heated in the firebox, is decomposed into carbon and hydrocarbon gases of different kinds. As the actions that take place in the burning of these hydrocarbons are too complicated to be within the scope of this paper, the burning of methane alone will be considered in connection with the combustion of coal.

75. The two main classes of coal are hard coal, or anthracite, and soft coal, or bituminous coal. It is customary to state the composition of a coal by giving the percentages of fixed carbon, volatile matter, moisture, and ash that it contains. All coal contains moisture, which may be there when the coal is mined or may get into it during or after transportation. The ash is the refuse that is left after the coal is burned, and consists of clay, sand, iron, and other substances that do not burn. The **volatile matter** includes all the gases and vapors that are driven off when a sample of dry coal is heated without burning. The **fixed carbon** is the carbon contained in the solid mass of coke that remains after the gaseous constituent, or volatile matter, has been driven off.

As a very general average, the composition of anthracite may be taken as follows:

Constituents	Per Cent.
Fixed carbon	83
Volatile matter	4
Moisture	3.5
Ash	9.5

The average composition of bituminous coal will fall within the following limits:

Constituents	Per Cent.
Fixed carbon	40 to 61
Volatile matter	27 to 39
Moisture	1 to 17
Ash	6 to 17

Carbon, it will be observed, is the chief constituent of coal. It forms the solid part, or that which remains after the volatile matter has been distilled off by heating. The ash is made up of the incombustible impurities, such as slate, bone, iron, and some sulphur. The iron and sulphur in coal are often found combined in the form of a compound called *iron pyrites*, which

TABLE II

COMPOSITION AND HEATING VALUES OF AMERICAN COALS

(*United States Geological Survey*)

State	Nearest Town	Name of Seam	Kind	Grade	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Calorific Value B. T. U.
					Per Cent.					
Alabama.......	Horse Creek	Horse Creek	B	L N	1.55	32.10	53.71	12.64	.73	12,958
Alabama.......	Carbon Hill	Jagger	B	L N P	2.58	33.15	51.74	12.53	1.02	12,449
Alabama.......	Garnsey	Underwood	B	R	2.72	20.46	53.46	14.36	.55	12,461
Alabama.......	Belle Ellen	Youngblood	B	R	6.43	28.56	52.09	12.92	1.08	12,395
Alabama.......	Lehigh	Black Creek	B	R	5.51	25.05	53.28	16.08	1.40	11,932
Alabama.......	Dolomite	Pratt	B	R	2.86	25.80	63.98	7.36	.59	14,440
Arkansas......	Bonanza	Jenny Lind	S B	L	.74	16.26	73.66	9.34	1.90	13,961
Arkansas......	Denning	Spadra	S B	S	1.79	14.36	73.52	10.33	1.68	13,402
Arkansas......	Coal Hill	Denning	S B	L S	1.28	12.82	73.69	12.21	2.01	13,406
Arkansas......	Huntingdon	Huntingdon	S B	L	1.17	17.83	68.12	12.88	1.27	13,460
Arkansas......	Midland	Hartshorn	S B	L	5.47	16.27	66.57	11.69	2.02	12,690
California......	Tesla	Tesla	L	R	18.51	35.33	30.67	15.49	3.05	8,105
California......	Stone Canyon		B	R	4.86	47.74	41.03	6.37	4.26	12,727
Colorado	Lafayette	Laramie	B L	R	13.49	37.11	43.03	6.37	.58	10,546
Colorado	Sopris	Sopris	B	R	1.26	31.03	53.39	14.32	.64	12,929
Colorado	Bowen	Walsen	B	R	1.41	31.52	49.16	17.91	.68	12,127
Colorado	Rugby	Cameron	B	S	1.73	35.72	48.36	14.19	.81	12,366
Colorado	Berwind	Berwind	B	R	1.66	33.24	51.57	13.53	.64	13,019
Colorado	Oak Creek	Yampa	B	R	6.69	36.68	45.88	10.75	1.51	11,561
Colorado	New Castle		B		2.73	38.09	53.60	4.98	.54	13,372
Florida........	Orlando	Peat, air dried	P		21.00	51.72	22.11	5.17	.45	8,127

Georgia........	Menlo	Little River	B	L	3.80	15.88	65.83	14.49	1.27	12,791
Illinois........	O'Fallon	Belleville, No. 6	B	L N	6.28	38.92	41.08	13.72	4.25	11,448
Illinois........	Marion	Cartersville, No. 7	B	R	5.96	30.29	52.16	11.59	1.77	12,103
Illinois........	Coffeen	Pana, No. 5	B	R	5.13	32.68	47.46	14.73	4.45	11,158
Illinois........	Collinsville	No. 7	B	R	10.83	36.24	39.75	13.18	4.53	10,816
Illinois........	Cartersville	No. 7	B	R L	8.86	31.25	48.23	11.66	2.46	11,902
Illinois........	Livingston	No. 5	B	R	12.25	33.76	41.66	12.33	4.42	10,719
Illinois........	Zeigler	No. 7	B	L	10.72	29.86	50.06	9.36	.91	11,686
Illinois........	Herrin	No. 7	B	L	7.78	29.85	52.39	9.98	1.32	11,959
Indiana........	Terre Haute	No. 6	B	R	12.79	35.45	39.67	12.09	3.18	10,899
Indiana........	Seelyville	No. 3	B	R	7.88	36.85	41.07	14.20	5.14	11,146
Indiana........	Linton	No. 4	B	R	13.58	32.07	46.20	8.15	.91	11,419
Indiana........	Linton	No. 5	B	R	10.30	36.31	41.64	11.75	4.23	11,218
Indiana........	Brazil	Bottom Bed Brazil Block	B	S N	16.91	26.85	38.87	17.37	1.89	9,524
Indiana........	Maxville	No. 7	B	L	5.24	37.83	45.73	11.20	3.56	12,085
Iowa..........	Laddsdale	Middle	B	L S	5.21	31.76	46.51	16.52	5.20	11,392
Iowa..........	Marion Co.	Big Vein	B	R	4.25	37.02	41.74	16.99	5.20	11,129
Iowa..........	Altoona	Third	B	L	4.52	40.96	38.99	15.53	6.83	11,356
Iowa..........	Centerville	Mystic	B	L	10.03	37.27	41.22	11.48	4.46	11,227
Iowa..........	Chariton	Lower	B	R	9.22	32.71	44.52	13.55	3.42	10,989
Kansas........	Fleming	Lower Weir-Pittsburg	B	R	3.74	33.11	50.01	13.14	4.34	12,404
Kansas........	Scammon	Weir-Pittsburg	B	R	2.50	33.80	51.25	12.45	5.68	12,900
Kansas........	Jewett	Weir-Pittsburg	B	L	9.04	29.69	45.55	15.72	3.72	11,142
Kansas........	West Mineral	Weir-Pittsburg	B	L N	4.10	31.65	53.71	10.54	3.77	12,895
Kansas........	Atchison		B	L	3.57	37.00	46.80	12.63	8.33	12,337
Kentucky......	Straight Creek	Straight Creek	B	L	1.92	36.56	57.08	4.44	1.24	14,319
Kentucky......	Earlington	No. 11	B	L	5.36	38.99	46.27	9.38	3.72	12,539
Kentucky......	Barnsley	No. 9	B	R	5.85	36.90	46.96	10.29	3.60	12,292

TABLE II—*Continued*

State	Nearest Town	Name of Seam	Kind	Grade	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Calorific Value B. T. U.
					Per Cent.					
Kentucky......	Wheatcroft	No. 11	B	R	2.54	36.08	46.79	14.59	4.67	12,294
Kentucky......	Sturges	No. 13	B	R	5.46	30.99	55.63	7.92	1.18	13,239
Kentucky......	McHenry	No. 9	B	N	8.70	35.00	47.34	8.96	3.14	12,078
Kentucky......	Big Black Mt.	High Splint	B	L	1.60	36.03	58.56	3.81	.69	14,324
Kentucky......	Near Paintsville	No. 1	B	R	5.12	36.49	55.63	2.76	.57	13,743
Maryland......	Frostburg	Big Vein	S B	R	.74	18.14	73.83	7.29	.86	14,555
Maryland......	Near West'nport		S B	R	2.33	16.11	68.43	13.13	1.49	13,255
Missouri.......	Bevier	Bevier	B	R	9.14	34.53	39.02	17.31	5.30	10,451
Missouri.......	Higbee		B	R	12.92	33.64	39.82	13.62	5.03	10,548
Missouri.......	Novinger		B	N	16.36	29.12	35.01	19.51	3.53	9,007
Missouri.......	Barnett		B	R	5.39	44.91	44.47	5.23	5.55	13,529
Missouri.......	Huntsville		B	L	2.49	45.44	38.79	13.28	6.34	12,213
Montana......	Bridger	Bridger	L	S	8.56	32.36	45.69	13.39	.54	10,685
Montana......	Red Lodge	No. 1	L	S	7.34	37.92	42.17	12.57	1.10	10,269
Montana......	Bear Creek	No. 2	L	S	8.21	37.98	47.67	6.14	1.47	11,422
New Mexico...	Blossburg	Raton	B	R	2.72	31.85	50.86	14.57	.69	12,539
New Mexico...	Gibson	Weaver	B L	L S	10.86	35.14	46.90	7.10	.64	11,435
New Mexico...	Van Houten	Raton	B	R	3.45	32.00	47.82	16.67	.73	11,893
North Dakota.	Williston	Cedar Coulee	L	R	16.70	37.10	39.49	6.71	.63	9,491
North Dakota.	Lehigh	Lehigh	L	R	15.42	38.73	33.61	12.24	2.02	9,061
Ohio..........	Mineral City	No. 5	B	L	4.49	40.55	47.43	7.53	2.93	13,291
Ohio..........	Bellaire	No. 8	B	R	4.14	39.30	47.18	9.38	3.96	13,381

Ohio..........	Near Wellston	No. 4	B	R	7.71	38.32	42.02	11.95	4.61	11,515
Ohio..........	Shawnee	No. 6	B	R	9.90	33.66	44.86	11.58	1.81	11,279
Ohio..........	Danford	No. 7	B	L	6.65	33.94	48.86	10.55	3.13	12,179
Ohio..........	Dixie	Hocking, No. 6	B	R	7.55	38.00	46.08	8.37	2.84	12,128
Ohio..........	Bradley	No. 8	B	L N	3.53	37.45	49.90	9.12	3.47	13,072
Oklahoma	Panama		S A	R	.64	14.29	76.66	8.41	1.24	14,083
Oklahoma	Henryetta	Henryetta	B	L	3.87	35.73	50.05	10.35	1.99	12,620
Oklahoma	Hartshorne	Hartshorne	B	R	1.70	37.19	49.79	11.32	1.56	12,969
Oklahoma	Edwards	McAlester	B	R	3.45	37.45	47.82	11.28	3.67	12,469
Oklahoma	Lehigh	Lehigh	B	L	4.91	37.79	43.90	13.40	4.02	11,389
Pennsylvania ..	Ellsworth	Pittsburgh	B	L N	1.47	34.83	57.59	6.11	.89	14,155
Pennsylvania ..	Hastings	D	S B	R	.36	22.67	68.78	8.19	1.65	14,062
Pennsylvania ..	Wehrum	B	S B	R	.34	18.12	71.45	10.09	3.88	14,193
Pennsylvania ..	Connellsville	Pittsburgh	B	R	.97	29.09	60.85	9.09	.90	13,952
Pennsylvania ..	Ehrenfield	Lower Kittanning	S B	R	.63	17.32	75.22	6.83	.97	14,706
Pennsylvania ..	White	Upper Freeport	B	R	1.09	28.71	57.87	12.31	1.56	13,406
Pennsylvania ..	Loydell	Miller	S B	R	.38	16.10	74.69	8.83	1.55	14,267
Pennsylvania ..	Huff	Pittsburgh	B	R	.91	29.03	59.57	10.49	1.03	13,738
Pennsylvania ..	Kimmelton	Lower Kittanning	S B	R	.50	17.75	70.12	11.63	2.09	13,783
Pennsylvania ..	Scranton		A	S	2.08	7.27	74.32	16.33	.77	12,472
Rhode Island..	Cranston		G A	R	.42	5.02	75.11	19.45	.07	11,212
Tennessee	Fork Ridge	Mingo	B	R	1.87	33.93	52.71	11.49	1.63	12,942
Tennessee	Brushy Mt.	Petros	B	R	1.35	35.13	53.32	10.20	3.38	13,421
Tennessee	Coalmount	Sewanee	B	L	1.36	27.96	56.22	14.46	.96	12,843
Tennessee	Gatliff	Regal Block	B	R	2.25	35.68	54.79	7.28	1.02	13,480
Tennessee	Waldensis	Lower Sewanee	B	R	1.02	28.43	55.69	14.86	.80	12,886
Tennessee	Gatliff	Log Mountain	B	R	1.95	36.97	54.05	7.03	1.01	13,734
Texas..........	Hoyt		L	R	9.76	37.51	42.77	9.96	.70	10,228
Texas..........	Olsen		L	R	9.88	36.77	43.65	10.30	1.30	10,287
Texas..........	Crockett		L	R	13.40	42.75	29.00	14.85	1.04	9,358
Utah..........	Price		B		2.34	43.68	48.92	5.06	.57	13,671

TABLE II—*Continued*

State	Nearest Town	Name of Seam	Kind	Grade	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Calorific Value B. T. U.
					Per Cent.					
Virginia.......	Pocahontas	No. 3	S B	R	1.63	17.17	75.34	5.86	.75	14,672
Virginia.......	Tom's Creek	Upper Vanner	B	L	.87	32.36	62.19	4.58	.68	14,796
Virginia.......	Blacksburg	Big Seam	A	P	4.80	10.12	67.05	18.03	.63	11,961
Virginia.......	Darby	Darby	B	L	2.40	37.64	55.54	4.42	.81	14,224
Virginia.......	Richlands	No. 4	B	R	.65	24.28	64.77	10.30	1.27	13,963
Washington....	Renton		B L	R	5.20	36.54	45.68	12.58	.80	11,291
Washington....	Roslyn	Roslyn	B	L	1.88	36.97	48.73	12.42	.38	12,751
Washington....	Carbonado	No. 3	B	R	4.66	29.07	50.31	15.96	.45	12,132
Washington....	Taylor	No. 4	B	R	6.20	34.20	41.37	18.23	.69	10,888
West Virginia..	Kingmont	Pittsburgh	B	R	1.35	36.92	55.36	6.37	.90	14,164
West Virginia..	Clarksburg	Pittsburgh	B	R	1.12	37.65	52.60	8.63	2.56	13,937
West Virginia..	McDonald	Sewell	S B	R	.68	23.28	70.91	5.14	.91	14,765
West Virginia..	Winifrede	Winifrede	B	R	1.50	37.16	56.39	4.95	1.35	14,247
West Virginia..	Rush Run	Fire Creek	S B	R	.64	21.74	72.53	5.09	.66	14,942
West Virginia..	Big Sandy	No. 8	S B	R	.62	18.05	74.38	6.95	.69	14,733
West Virginia..	Page	Ansted	B	R	1.17	31.87	62.95	4.01	.91	14,821
West Virginia..	Powellton	Powellton	B	R	1.01	29.53	62.67	6.79	.80	14,171
West Virginia..	Bretz	Bakerstown	B	R	1.00	27.99	62.68	8.33	1.49	14,225
West Virginia..	Bretz	Upper Freeport	B	R	.98	28.72	61.87	8.43	.90	14,139
West Virginia..	Monarch	Cedar Grove	B	R	1.58	35.21	55.50	7.71	1.24	13,757
West Virginia..	Coalton	Roaring Creek	B	L	.65	29.20	59.97	10.18	.99	13,828
West Virginia..	Springhill	Black Band	B	L	1.95	36.24	54.42	7.39	.66	13,694
Wyoming......	Hanna		B L	R	9.21	45.27	42.04	7.48	.29	11,009
Wyoming......	Rock Spring		B L	R	6.00	38.69	51.68	3.63	.86	12,519
Wyoming......	Cambria		B	R	2.73	37.61	37.40	22.26	4.17	10,364
Wyoming......	Kemmerer		B L	R	8.68	41.31	46.49	3.52	.55	11,621
Wyoming......	Monarch		B L	R	17.69	37.96	39.56	4.79	.63	10,355

is largely responsible for the formation of clinkers. Soft coal contains a much smaller percentage of fixed carbon than hard coal and a correspondingly greater amount of volatile matter. The parts of the coal that burn and give off heat in burning are, taken together, known as the **combustible.**

76. Calorific Value.—The value of a coal as fuel depends on the quantity of combustible that it contains and on the **calorific value,** or **heating value,** which is the quantity of heat developed by the complete combustion of one pound of the coal. The calorific value cannot be measured in pounds or gallons, like solids or liquids, because heat is not a substance; therefore, it is necessary to measure the heat developed by the effect it produces, and this is commonly done by noting the number of degrees rise of temperature produced in a known quantity of water by the heat.

77. If a pound of water at 39.2° F. is heated until its temperature is one degree greater, or 40.2° F., the quantity of heat added to the water is one **British thermal unit,** abbreviated B. T. U. This is the unit by which heat is usually measured, just as the inch is the unit for measuring short lengths and the gallon for measuring liquids. Thus, the British thermal unit is the quantity of heat required to raise one pound of water one degree Fahrenheit. So, to find the calorific value of a fuel, it is only necessary to burn a pound of it and observe the rise of temperature that the heat of burning produces in a known weight of water. For example, suppose that the heat developed by burning a pound of a certain coal was sufficient to heat 200 pounds of water from 40° F. to 108° F., or an increase of 68° F. The heating value of that coal then must be $68 \times 200 = 13,600$ B. T. U. In other words, the product of the rise of temperature and the weight of water is the heating value per pound.

78. The calorific value of a pound of carbon burned completely is 14,500 B. T. U. and of hydrogen is 63,200 B. T. U. Coals, being made up of carbon and hydrogen in varying proportions, have different heating values, depending on the relative amounts of carbon and hydrogen. In recent years it has

TABLE III

COMPOSITION AND HEATING VALUES OF CANADIAN COALS

(*Canadian Department of Mines*)

Field	Town	Mine	Seam	Grade	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Calorific Value B. T. U.
					Per Cent.					
Alberta:										
Edmonton.........	Strathcona	Strathcona		L	22.7	41.0	47.6	11.4	.4	10,728
Edmonton.........	Edmonton	Parkdale		L	22.5	37.8	51.3	10.9	.4	10,908
Edmonton.........	Edmonton	Standard		L	23.5	42.0	49.9	8.1	.4	11,358
Belly River........	Taber	Taber		L	13.0	36.0	49.9	14.1	1.4	11,034
Belly River........	Lethbridge	Galt		L	8.4	37.5	51.5	11.0	.8	11,719
Lundbreck.........	Lundbreck	Lundbreck		R	5.0	30.1	40.2	29.7	1.2	9,810
Frank-Blairmore....	Passburg	Leitch	Bellevue No. 1	R	1.9	27.0	55.1	17.9	.6	12,240
Frank-Blairmore....	Hillcrest	Hillcrest		R	3.0	29.3	55.4	15.3	.6	12,456
Frank-Blairmore....	Lille	Lille	No. 1	R	.9	27.6	56.9	15.5	.8	12,384
Frank-Blairmore....	Bellevue	Bellevue	No. 1	R	1.7	25.0	58.6	16.4	.5	12,474
Coleman..........	Coleman	Denison	No. 2	R	2.0	25.1	55.1	19.8	.4	11,718
Coleman..........	Coleman	Denison	No. 4	R	2.0	23.9	59.9	16.2	.6	12,528
Canmore-Bankhead.	Canmore	A No. 1		R	1.2	17.2	70.5	12.3	.8	13,212
Canmore-Bankhead.	Banff	Bankhead		P	1.0	11.8	76.0	12.2	.6	13,320
Canmore-Bankhead.	Banff			B	1.1	12.6	71.5	15.9	.6	12,672
British Columbia:										
Crows Nest Pass...	Michel	No. 3		L	1.4	24.8	62.7	12.5	.5	13,266
Crows Nest Pass...	Michel	No. 7		L	1.9	22.6	65.5	11.9	.4	13,356
Crows Nest Pass...	Michel	No. 8		L	3.0	24.1	65.7	10.2	.6	13,482
Crows Nest Pass...	Hosmer	Hosmer	No. 2	R	1.7	21.3	63.4	15.3	.3	12,708
Crows Nest Pass...	Hosmer	Hosmer	No. 6	R	2.6	25.6	62.0	12.4	.6	13,086
Crows Nest Pass...	Hosmer	Hosmer	No. 8	R	4.0	28.0	64.5	7.5	.6	13,986
Crows Nest Pass...	Fernie	Coal Creek No. 2		R	2.2	26.3	64.7	9.0	.5	13,822
Crows Nest Pass...	Fernie	Coal Creek No. 5		R	1.6	24.0	65.2	10.8	.5	13,482
Nicola Valley.......	Coutlee	Middlesboro No. 1		R	4.4	39.1	46.4	14.5	.9	11,682

Nicola Valley	Coutlee	Middlesboro No. 2		R	2.9	39.0	48.1	12.9	.7	12,068
Vancouver Island	Wellington	Extension		L	1.8	40.1	49.8	10.1	.4	13,158
Vancouver Island	Nanaimo	Esplanade No. 1	Douglas	L	2.2	41.2	48.5	10.3	.9	12,834
Vancouver Island	Nanaimo	Esplanade No. 1	Newcastle	L	2.4	41.5	46.6	11.9	1.3	12,474
Vancouver Island	Cumberland	Union No. 4	Newcastle	L		31.6	56.5	11.9	1.0	12,870
Vancouver Island	Cumberland	Union No. 7	Newcastle	L		28.0	60.1	11.9	.9	12,978
Vancouver Island	Suquash	Suquash				34.3	42.7	23.0	1.0	11,106
New Brunswick:										
Grand Lake	Minto	Kings		L	1.3	32.2	53.4	14.4	5.8	12,888
Nova Scotia:										
Sydney	Cape Breton	Port Morien	Gowrie	L		34.7	53.0	12.3	6.4	12,708
Sydney	Glace Bay	No. 7	Hub	L	3.5	36.5	57.6	5.9	2.4	13,860
Sydney	Glace Bay	No. 9	Harbour	L	2.4	38.6	55.5	5.9	3.7	14,004
Sydney	Glace Bay	No. 5	Phalen	L	3.4	35.0	59.5	5.5	1.8	14,040
Sydney	Glace Bay	No. 10	Emery	R	4.0	35.1	53.8	11.1	2.5	13,122
Sydney	Lingan	No. 12	Lingan	R	4.9	37.3	57.9	4.8	1.8	13,788
Sydney	Sydney Mines	Sydney No. 1	Main	L	3.5	37.4	55.4	7.2	2.9	13,770
Sydney	Sydney Mines	Sydney No. 3	Main	L	5.4	39.0	54.3	6.7	2.5	13,680
Inverness	Inverness	Inverness		L	9.3	40.0	49.6	10.4	6.0	12,150
Inverness	Port Hood	Port Hood		L	4.7	37.1	48.3	14.6	7.9	11,772
Pictou	Thorburn	Vale	6 Foot	L	2.1	32.1	50.6	17.3	1.0	12,024
Pictou	Stellarton	Allan Shaft	Foord	R	3.6	33.3	55.4	11.3	.6	13,230
Pictou	Stellarton	Albion	Third	R		29.8	55.5	14.7	1.4	12,852
Pictou	Stellarton	Albion	Cage Pit	R	3.6	31.4	58.1	10.5	.9	13,176
Pictou	Westville	Acadia	Main	L	1.8	26.0	64.8	9.2	.9	13,860
Pictou	Westville	Drummond	Main	L	1.4	24.7	60.8	14.5	2.5	12,960
Springhill	Springhill	No. 2		L	2.8	32.3	58.5	9.2	1.6	13,394
Springhill	Springhill	No. 3		L	2.8	33.5	55.0	11.5	1.8	12,996
Joggins	Chignecto	Chignecto		L	3.6	41.0	45.7	13.3	6.4	12,150
Joggins	River Herbert	Minudie		L	3.8	35.7	48.8	15.5	6.7	11,826
Joggins	Joggins	Joggins		L	1.3	36.6	44.8	18.6	5.4	11,592
Saskatchewan:										
Souris	Taylortown	Taylortown		L	28.6	49.0	42.9	8.1	.6	10,692
Souris	Estevan	Eureka		R	30.9	40.0	43.2	16.8	.5	9,648
Yukon:										
White Horse		Tantalus	Upper	M S		25.0	58.0	17.0	.5	12,060
White Horse		Tantalus	Middle	M S		26.7	54.1	19.2	.5	11,358
White Horse		Tantalus	Lower	M S		27.8	56.0	16.2	.5	12,222

become a general practice to buy coal on a B. T. U. basis—that is, to buy it on the basis of its calorific value expressed in heat units, or B. T. U., per pound, rather than on the grade of the coal or the name of the seam from which it is mined. Table II gives the composition and calorific values of a number of typical coals of the United States and Table III gives similar information for Canadian coals. It is to be noted that coals from the same locality vary considerably in composition and heating value. In these tables the letters used are explained as follows: In the column giving the kind of coal, A indicates anthracite; B, bituminous; B L, black lignite, or subbituminous; G A, graphitic anthracite; L, lignite; P, peat; S A, semianthracite; S B, semibituminous. In the column giving the grade of coal, L indicates lump; N, nut; P, pea; R, run of mine; S, slack; and a combination of letters represents a mixture, as, for example, L N refers to a mixture of lump and nut. The letters M S in Table III indicate mine sample; and B indicates buckwheat (anthracite).

In the case of the coals mentioned in Table II, the sulphur in the samples was determined separately; consequently, the sum of the moisture, volatile matter, fixed carbon, and ash is 100 for each kind of coal. In Table III, the sum of the volatile matter, fixed carbon, and ash is 100 for each coal, as the moisture and sulphur were determined separately. On account of this difference in methods of analysis, the values of the corresponding percentages, in the two tables cannot be compared directly.

79. Wood.—As a fuel, wood is divided into two classes: the hard woods, such as maple, oak, hickory, etc., and the soft woods, such as pine, birch, poplar, etc. The value, as fuel, of equal weights of different woods, when equally dry, is very nearly the same. In other words, 1 pound of maple is no better for fuel than 1 pound of pine or poplar, provided that both contain the same percentage of water. Water in fuel is very detrimental, every 10 per cent. of moisture reducing its value as a fuel about 12 per cent.

Wood cut in winter will retain, by the end of the following summer, about 40 per cent. of its water, while, after several years in a dry place, it still retains from 15 to 20 per cent. of it. If wood that has been thoroughly deprived of all moisture is exposed to the outside atmosphere, it will absorb about 5 per cent. of moisture in 3 days, after which it will continue to absorb moisture until it contains about 16 per cent.; it will then absorb no more.

The chemical composition of the various woods is nearly the same, and is about as follows for ordinary fire-wood:

	Per Cent.		Per Cent.
Carbon	37.50	Nitrogen	.75
Hydrogen	4.50	Water	25.00
Oxygen	30.75	Ash	1.50

Two and one-half pounds of good dry wood is generally assumed to evaporate as much water as 1 pound of good coal. A *cord* of wood consists of a pile 4 feet wide, 4 feet high, and 8 feet long.

MIXTURES

80. Definition.—A **mixture** may consist of two or more elementary substances, or compound substances, or both elementary and compound substances, mixed together, but not combined chemically. For example, gold and silver filings may be mixed together to form a mixture; iron filings and sand mixed together form another example; salt water is another instance of a mixture, while the atmosphere forms, perhaps, the most familiar example of all. Air is a mechanical mixture, consisting of twenty-three parts, by weight, of oxygen to seventy-seven parts of nitrogen. These gases are not combined chemically—they are simply mixed together.

81. Air.—The atmosphere consists of a fluid called **air,** that completely surrounds the earth to an estimated height of about 40 miles. It is held in place by its own weight. The weight of the atmosphere is such that it exerts a pressure of 14.7 pounds per square inch at the sea level—a pressure sufficient to balance a column of mercury 30 inches high, or a column of water 34 feet high. This pressure is sufficient to force the air into all holes, crevices, and porous substances, so that it penetrates the earth to a considerable depth, its density increasing with the depth.

Ordinarily, pure air has no color, taste, or odor; it consists chiefly of a mixture of 4 volumes of nitrogen and 1 volume of oxygen, or, by weight, of about 3.5 parts of nitrogen and 1 part of oxygen. It is through the medium of the atmosphere that the oxygen so necessary to animal and vegetable life, and to the process of combustion, is furnished in its free state. At 62° F., 13.14 cubic feet of air weighs 1 pound.

THEORY OF COMBUSTION

GENERAL PRINCIPLES

82. Definition.—Combustion, or burning, as it is properly called, is a very rapid chemical combination of oxygen of the air with any combustible material, producing both heat and light. Oxygen has a very strong affinity for most elements, and especially for carbon, with which it combines very rapidly whenever they come in contact with each other at a sufficiently high temperature. The more rapid the combination, the greater is the quantity of heat given off in a unit of time, and consequently the higher the temperature produced.

83. The combustible substances in coal, wood, oil, etc. are carbon and hydrogen. The combustion of fuel, therefore, is the rapid chemical combination of the carbon and hydrogen in the fuel with the oxygen of the air. In order to bring about combustion, (three conditions are necessary: first, the combustible or fuel; second, air containing the oxygen needed to support combustion; and third, a sufficiently high temperature to cause the combustible elements to start to burn. (The temperature to which a combustible substance must be heated before it will begin to burn is called the **igniting temperature.**) Each substance has its own igniting temperature, that of coal being in the neighborhood of 1,800° F.

84. Illustration of Combustion.—A familiar illustration of the process of combustion is furnished by the lighting and burning of a match. The match may be considered as the fuel, the oxygen is supplied by the air, and the substance forming the tip of the match is employed to bring the wood of the match to the igniting temperature. The igniting temperature of the chemical on the tip of the match is much lower than that of the wood; therefore, when the match is struck on a rough surface the friction between the head and the rough surface generates enough heat to raise the temperature of the chemical to the igniting point and so sets it on fire. Its burning in turn raises the temperature of the wood to the igniting temperature, or about 1,000° F. This takes place almost instantly, with the result that the wood and the oxygen start to combine, and the match is said to burn. It will be noticed, however, that the entire surface of the match is not ignited at one time, but that it first begins to burn next the chemical on the tip, and gradually burns toward the other end of the match. The reason for this is that only a portion of the wood near the flame is heated to the igniting temperature. This takes fire, and heats another portion of the wood nearest it to the igniting temperature, which in turn burns, and so on gradually until the match is consumed.

85. Products of Combustion.—The combustible elements in coal are principally carbon and hydrogen, for both of which oxygen has a strong affinity; however, the affinity of oxygen for hydrogen is stronger than that of oxygen for carbon. The result is that when the hydrocarbons in fuel are broken up into carbon and hydrogen, the hydrogen burns first, because the oxygen unites with it in preference to uniting with the carbon. The burning of the hydrogen in coal results in the formation of water, whose chemical formula is H_2O. This formula indicates that two atoms of hydrogen combine with one atom of oxygen to form one molecule of water, or H_2O; but as the firebox is at a high temperature, the water thus produced is converted into steam by the heat and escapes through the stack, along with the smoke and other gases. Steam is therefore the product of the combustion of the hydrogen contained in the fuel.

86. When carbon burns, it may produce either or both of two different gases, depending on the conditions under which combustion takes place. Suppose that the amount of air supplied to the coal is sufficient to furnish two atoms of oxygen for every atom of carbon in the fuel. Then the carbon will combine with the oxygen in the proportion of one atom of carbon to two atoms of oxygen, and each of these combinations results in the formation of a molecule of CO_2, which is the chemical formula of **carbon dioxide.** This is a colorless, tasteless, odorless gas. Whenever there is enough oxygen present, carbon will always burn to carbon dioxide. This gas represents the product of the complete combustion of carbon; that is, the carbon has combined with as much oxygen as it can possibly take up. Carbon dioxide is a dead gas; that is, it cannot be burned, because it is the result of a combustion that is complete.

87. If the quantity of air supplied is too scanty, the result will be incomplete combustion of the carbon. Under such conditions there will not be enough oxygen present to supply each atom of carbon with two atoms of oxygen, and so these two elements will unite in another proportion. Each atom of carbon will unite with one atom of oxygen to form one molecule of **carbon monoxide,** the chemical formula for which is CO. In other words, the carbon combines with only *half* as much oxygen as when it burns to carbon dioxide. Therefore, carbon monoxide is the product of the incomplete combustion of carbon. It also is a colorless, tasteless, odorless gas; but it is different from carbon dioxide because it can be burned. If, after carbon monoxide is formed, it is mixed with a fresh supply of air at a sufficiently high temperature, it will take up additional oxygen and burn to carbon dioxide. This means that each molecule of CO will take up one more atom of O, or oxygen, and thus become CO_2, or carbon dioxide.

88. There is another way in which carbon monoxide may be formed. If a deep fire is carried on a grate, some of the carbon at the bottom of the fire will burn and produce carbon dioxide and this gas will be carried by the draft up through the fire. In the heart of the fire bed there will be a layer of hot fuel that will be practically pure coke, which consists of carbon without any gases in it. The carbon-dioxide gas, rising and mixing with this hot coke, is broken up, or decomposed, by the heat, into carbon monoxide and free oxygen. The oxygen thus set free combines with some of the carbon in the coke and forms carbon monoxide, so that the net result is that the carbon dioxide is converted into carbon monoxide by taking up additional carbon. This is a very common action in the fire on a locomotive grate. As the monoxide rises into the firebox, however, it is mixed with fresh air admitted above the fire and so is burned to carbon dioxide before it can escape to the stack.

89. As carbon monoxide is capable of being burned, it should not be allowed to escape; otherwise, it will carry away combustible matter and so cause a direct loss. The object should be to burn all carbon to carbon dioxide, as by so doing the greatest possible amount of heat is obtained from the combustion. If a pound of carbon is given enough air to enable it to burn to carbon dioxide, it will yield 14,500 B. T. U. But if the air supply is cut down so that it can burn only to carbon monoxide, the amount of heat developed will be only 4,400 B. T. U. In other words, the incomplete combustion of carbon results in a direct loss of 10,100 B. T. U. In the first case, one part of carbon combines with two parts of oxygen and forms carbon dioxide, which produces a great amount of heat; and in the second case, one part of carbon combines with only one part of oxygen and forms carbon monoxide, producing only one-third as much heat. With half enough oxygen it does only one-third the work that it could do with sufficient oxygen, and oxygen is free—it costs nothing.

90. To change one pound of carbon into the best heat-producing gas takes, theoretically, about 152 cubic feet of air. If half this amount is supplied, the pound of carbon will only use the oxygen contained in 76 cubic feet of air, and will only be one-third as valuable. In each case the same amount of coal will be used, but in the latter case, on account of imperfect burning, only one-third the amount of heat will be generated, and so only one-third the amount of water will be changed into steam, and steam is what is wanted. At the same time an excess of smoke will be made, and smoke is not wanted. Oxygen is free, while coal costs money; therefore, enough oxygen should be supplied by the air to make perfect combustion and save coal.

91. To follow up this process, it is readily seen that if all the carbon, both fixed and gaseous, could be supplied with all the oxygen needed to change it into carbon dioxide, it would evaporate the same amount of water into steam that 3 pounds of carbon would in case it had so small a supply of oxygen that it could only make carbon monoxide. With a full supply of oxygen, a saving of two-thirds of the coal would, theoretically, take place. But it never happens that all the carbon changes into the very hot gas, as the fluctuating conditions of the supply of coal and air to the fire prevent ideal proportions, so that the fireman must be content with saving as much as possible.

AIR REQUIRED FOR COMPLETE COMBUSTION

92. Carbon.—To burn carbon completely, twelve parts of it, by weight, must combine with thirty-two parts of oxygen; therefore, for every pound of carbon burned, $32 \div 12 = 2.67$ pounds of oxygen must be supplied. As only about 23 per cent. of the air is oxygen, $2.67 \div .23 = 11.6$ pounds of air must be supplied for every pound of carbon consumed; that is, 11.6 pounds of air contains 2.67 pounds of oxygen, and, theoretically, should supply sufficient oxygen to completely burn 1 pound of carbon. The remainder of the 11.6 pounds of air, viz., 8.93 pounds of nitrogen, passes off with the $2.67 + 1 = 3.67$ pounds of carbon dioxide, as the products of combustion.

93. Hydrogen.—The hydrogen of the fuel combines in the proportions, by weight, of two parts of hydrogen to sixteen parts of oxygen, forming water, which, of course, is in the form of vapor. One pound of hydrogen therefore requires $16 \div 2 = 8$ pounds of oxygen for complete combustion. Since

TABLE IV

AIR REQUIRED FOR COMBUSTION OF VARIOUS SUBSTANCES

Combustible	Weight of Oxygen Required to Burn 1 Pound of Combustible Pounds	Quantity of Air at 60° F. Required to Supply the Necessary Oxygen*		Products of Combustion Pounds
		Pounds	Cubic Feet	
One Pound of				
Carbon, burning to carbon dioxide	2.670	11.60	152	3.670 carbon dioxide and 8.93 nitrogen
Carbon, burning to carbon monoxide	1.335	5.80	76	2.335 carbon monoxide and 4.465 nitrogen
Carbon monoxide, burning to carbon dioxide	.570	2.48	33	1.570 carbon dioxide and 1.91 nitrogen
Hydrogen	8.000	34.80	457	26.80 nitrogen and 9 water
Methane (carbureted hydrogen)	4.000	17.40	230	2.745 carbon dioxide, 13.405 nitrogen, and 2.25 water
Average coal	2.530	11.00	140	2.980 carbon dioxide, 8.52 nitrogen, and .45 water
Wood	1.400	6.08	80	1.830 carbon dioxide, 6.08 nitrogen, and .546 water
Petroleum	3.460	15.00	197	3.170 carbon dioxide, 11.55 nitrogen, and 1.28 water

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*To determine the quantity of air, in cubic feet, from the weight, in pounds, multiply by 13.14.

each pound of air contains .23 pound of oxygen, 8÷.23=34.8 pounds of air will be required for the complete combustion of 1 pound of hydrogen. The products of combustion will be 34.8−8=26.8 pounds of nitrogen, and 8+1=9 pounds of water.

94. Carbon Monoxide.—The combustion of 1 pound of carbon, to form carbon monoxide, requires but half as much oxygen as would be required to form carbon dioxide; therefore, but half the air is required. Since it requires 2.67 pounds of oxygen, or 11.6 pounds of air, to burn 1 pound of carbon to carbon dioxide, to burn it to carbon monoxide would require 1.335 pounds of oxygen, or 5.8 pounds of air, and the products of combustion would be 2.335 pounds of carbon monoxide and 4.465 pounds of nitrogen.

95. Carbon Dioxide.—Carbon monoxide, in burning to carbon dioxide, combines with oxygen in the proportions, by weight, of twenty-eight parts of carbon monoxide to sixteen parts of oxygen. One pound of carbon monoxide therefore requires 16÷28=.57 pound of oxygen, or .57÷.23=2.48 pounds of air, for complete combustion. The products of combustion in this case are: 1+.57=1.57 pounds of carbon dioxide, and 2.48−.57=1.91 pounds of nitrogen.

The theoretical quantities of oxygen and of air necessary for complete combustion of various combustibles, together with the products of combustion in each case, are given in Table IV.

HEAT OF COMBUSTION

96. When carbon burns to carbon dioxide, it combines with the greatest amount of oxygen possible, and therefore produces its greatest quantity of heat; when it burns to carbon monoxide, it combines with but half the oxygen possible, and produces less than one-third the heat that would be generated were it burned to carbon dioxide. This is shown in Table V, which gives the total number of heat units produced by the complete combustion of various combustibles.

By completely burning the carbon, 14,500 heat units is produced, while if it is only burned to carbon monoxide, only 4,400 heat units is produced; that is, 10,100 heat units is wasted for every pound of carbon incompletely burned.

TABLE V

CALORIFIC VALUES OF VARIOUS COMBUSTIBLES

Combustible	Total Heat of Combustion of 1 Pound of Combustible B. T. U.
One Pound of	
Hydrogen	62,000
Carbon, burned to carbon monoxide	4,400
Carbon, burned to carbon dioxide	14,500
Carbon monoxide, burned to carbon dioxide	10,100
Methane (carbureted hydrogen)	23,500
Coal (average composition)	14,100
Wood	7,950
Petroleum	21,000

TEMPERATURE OF COMBUSTION

97. Theoretical Temperatures.—In Table V is given the total quantity of heat generated in burning 1 pound of a certain fuel. In Table IV is given the weight and nature of the products of combustion.

The quantity of heat mentioned in Table V will heat the gaseous products of combustion to a certain temperature, depending on their weight and on the number of heat units necessary to raise 1 pound of the gases 1° F. Of course, as the weight and nature of the products of combustion differ for different fuels, the temperatures due to their combustion will differ.

The theoretical temperature of combustion of the fuels in Table VI has been calculated on the assumption that just enough air for complete combustion is supplied, no allowance being made for losses of heat. These theoretical temperatures are never attained in practice, for the following reasons: Combustion is seldom complete; excess of air is always supplied; fuel is never entirely consumed; heat is lost by radiation; and moisture present in the fuel absorbs some of the heat.

TABLE VI

THEORETICAL TEMPERATURES OF COMBUSTION

Combustible	Resulting Temperature of Combustion Degrees Fahrenheit
Hydrogen	5,750
Carbon, burning to carbon dioxide	4,872
Carbon, burning to carbon monoxide	2,668
Carbon monoxide, burning to carbon dioxide	5,367
Methane (carbureted hydrogen)	9,624
Seasoned wood	2,867
Average bituminous coal	4,080
Average anthracite coal	4,170
Coke or charcoal	4,350

PROCESSES OCCURRING IN THE FIREBOX

98. Tearing-Down Process.—There are two processes constantly going on in a locomotive firebox, one of which is called the *tearing-down process* and the other the *building-up process*. The **tearing-down process** is the breaking up of the fuel into its elements, and requires heat. The **building-up process** is the recombination of the elements separated from the fuel during the tearing-down process with the oxygen of the air to form new compounds, and produces heat. Oxygen will not unite with compounds, but only with elements. Coal is a compound consisting chiefly of carbon and hydrogen, some of the carbon being combined with the hydrogen to form the volatile matter, or hydrocarbons, the remainder being the fixed carbon. The hydrocarbons must be broken up or separated into their elements, carbon and hydrogen, before oxygen will unite with them. The fixed carbon, as it does not exist in combination with any other element, will burn as soon as it is heated to its igniting temperature.

99. The breaking down or separation of the hydrocarbons, as well as the heating of the fixed carbon to its igniting temperature, requires heat. Therefore, when coal is thrown on the fire, it first absorbs heat. The moisture that may be present in the coal in its natural state, or moisture due to wetting down the coal, is first evaporated, after which the hydrocarbon gases begin to pass off at a temperature of about 400° F. The driving off of these gases continues until the coal is heated to about 900° F., when the greater part of the gases will be given off, the fixed carbon of the coal being left on the grates. As already explained, the hydrocarbon gases are in a compound form, being made up of free carbon and hydrogen, and in this form will not burn. They must be torn down, or separated into their elements, carbon and hydrogen, before burning is possible, and this process requires a far higher temperature than is necessary to distill the gases from the coal. The temperature necessary to break up the hydrocarbon gases into their elements is about 1,800° F., and assuming that the firebox is at this temperature, the hydrocarbon gases are separated into their elements, free carbon and hydrogen. The iron pyrites that may be present in the coal are also heated and separated into iron and sulphur. This completes the tearing-down process, which is accomplished by the expenditure of heat. The building-up process, which results in the formation of heat, will next be considered.

100. Building-Up Process.—It will be assumed first that the conditions in the firebox are such as to insure perfect combustion, which means that the elements present combine in the correct proportions to insure that the maximum temperature will be generated. As already stated, the building-up process refers to the combination of the elements separated from the fuel, during the tearing-down process, with the oxygen of the air to form new compounds, heat being evolved during the recombination. If the firebox temperature is maintained at or above the igniting temperature of hydrogen and carbon, there will be a combination of oxygen with the hydrogen and carbon set free by the tearing down of the hydrocarbons. When oxygen combines with carbon and hydrogen under the above conditions, certain results always occur in accordance with certain fixed laws. Each atom of carbon under favorable conditions combines with two atoms of oxygen and forms an entirely new compound, known as carbon dioxide, represented by the chemical formula CO_2; and one atom of oxygen combines with two atoms of hydrogen and forms steam, which, when cooled, becomes water, indicated by the chemical formula H_2O. This completes the burning of the carbon and hydrogen of the methane, the only hydrocarbon that will be considered, the products of combustion being carbon dioxide and water vapor.

101. The conditions favorable to the burning of the methane will also result in the breaking up and burning of the other hydrocarbons of the fuel. In order to break up the hydrocarbons, it is necessary to maintain the firebox temperature above 1,800° F.; otherwise, these gases will not be separated into their elements, and will pass off unburned, thus wasting a valuable heat-producing part of the fuel. The carbon and hydrogen will burn at a lower temperature than that required to break up the gases in which they are combined, the igniting temperature of the former being about 930° F. and of the latter about 1,200° F. The remaining carbon, or fixed carbon, of the fuel remains on the grates until consumed, and assuming that there is a high enough temperature and a sufficient supply of oxygen, it unites with oxygen in the same proportion as the free carbon, to form carbon dioxide.

102. During the burning of the hydrocarbons and the fixed carbon, the iron pyrites present separate into the elements sulphur and iron. The sulphur then unites with oxygen and forms a gas known as sulphur dioxide, and the iron combines with oxygen and forms iron oxide. This latter substance is molten when hot, and in combination with the ashes and other impurities in the coal is largely responsible for clinkers. Although the iron pyrites burn, yet the amount of heat produced by their combustion is small in comparison to the trouble they make in forming clinkers.

103. The tearing down of the hydrocarbon gases into their elements, carbon and hydrogen, and their recombination or building up with oxygen, practically occur instantaneously and if desired may be considered as one and the same event. A small percentage of heat is required to break the fuel into its elementary parts in comparison with the heat produced by the same elements combining with oxygen to form the compounds carbon dioxide and water. These compounds are products of combustion and are gases. If the fuel were composed of carbon and hydrogen only, as in the case of natural gas, for example, and during burning these elements combined completely with oxygen, the gases from burning would be invisible.

104. The fixed carbon of the coal and the carbon of the hydrocarbons do not always burn completely. If there is not enough oxygen present so that each atom of carbon can combine with two atoms of oxygen in the building-up process, some of the carbon will combine with oxygen in the proportion of one atom of carbon to but one atom of oxygen and form another colorless compound gas known as **carbon monoxide,** represented by the formula CO. The heat produced during the formation of carbon monoxide is about one-third as much as is produced when carbon burns to carbon dioxide. The unconsumed carbon that escapes due to the absence of oxygen with which to combine is white hot when in the firebox, but when it cools it turns black and forms smoke. Black smoke is then the unburned carbon of the hydrocarbon gases, and represents a serious fuel loss.

105. **Fuel-Bed Actions.**—Experiments have shown that the fuel bed on which the fixed carbon burns may be divided into three zones, as illustrated in Fig. 4, known as the oxidation, reduction, and distillation zones. As the air passes from the ash-pan through the grates, the oxygen combines with the carbon of the coal and forms carbon dioxide, generating all the heat due to this union. This action occurs in the oxidation zone, which extends three or four inches above the grate line.

The carbon dioxide, after leaving the oxidation zone, passes through the layers of coke in the reduction zone and there each molecule of carbon dioxide takes up another atom of carbon and is reduced to two molecules of carbon monoxide. As the formation of carbon dioxide results in the liberation of heat, so in its reduction or breaking down in the reduction zone it absorbs heat, with the result that a cooling action takes place in this zone. The carbon monoxide formed in the reduction zone rises into the distillation zone, where it mingles with the gases that are being distilled, or driven off, from the green coal by the heat, and the mixture of gases rises into the firebox. If there is not sufficient oxygen present to unite with them and burn the carbon monoxide to carbon dioxide, it will pass away in an unburned condition with a resulting loss of heat. If sufficient oxygen is present above the fuel bed, the carbon monoxide will combine with another atom of oxygen and again form carbon dioxide. To burn bituminous coal properly, then, air for the combustion of a portion of the coke can be supplied through the grates, while a sufficient quantity for the combustion of the gases and the upper layers of coal should be admitted above the fire.

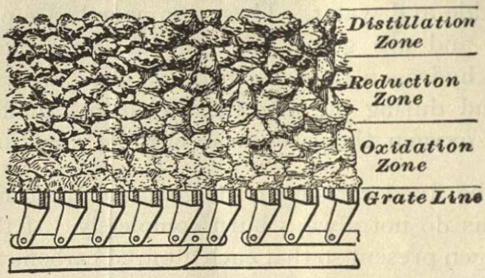

FIG. 4

106. Proper Air Supply.—The proper supply of air to the fire is one of the most important matters connected with economical firing. It takes about 160 cubic feet of air to supply oxygen for the complete burning of 1 pound of ordinary soft coal, and as each scoopful of coal weighs from 14 to 20 pounds, it will take from 2,200 to 3,200 cubic feet of air to supply the oxygen necessary for its complete combustion. But it is not enough to take in only just sufficient air to furnish the oxygen needed to burn the carbon to carbon dioxide and the hydrogen to water. Every particle of carbon and hydrogen must be surrounded by a liberal supply of oxygen to insure complete combustion, and so 250 cubic feet of air, or nearly 19 pounds, has been found to be about the right amount for a pound of coal, or from 3,500 to 5,000 cubic feet of air for each scoopful. A box car 36 feet long, inside, by 8 feet wide and 8 feet high holds 2,300 cubic feet, which will give some idea of the vast amount of air that must pass through the firebox for each scoopful of coal fired.

107. Quantity of Water Evaporated.—In ordinary locomotive service 7 pounds of water evaporated by 1 pound of coal is a fair average duty; it is possible to raise this amount to 11 pounds. A gallon of water weighs about 8⅓ pounds. So, if 1 gallon of water is evaporated by the heat developed by burning 1 pound of coal, the results obtained are above the average.

COMBUSTION OF COAL

108. Bituminous Coal.—Coal is a compound substance, consisting chiefly of carbon and hydrogen, in which elements practically its entire heating properties lie. If these are completely burned, the coal will produce its greatest quantity of heat; on the other hand, if they are not completely burned, part of the heat that the coal should produce in burning will pass off as unburned gases and smoke.

When 100 pounds of average bituminous coal is heated, the hydrogen is driven off, taking some carbon with it, in combination, forming 30 pounds of carbureted-hydrogen gas, and leaving behind about 55 pounds of solid carbon. Thus, for every 100 pounds of coal there is about 55 pounds of solid carbon and 30 pounds of carbureted hydrogen to be burned, the remaining 15 pounds being waste, partly in the gaseous form and partly as solid matter. This means that the coal has .55 fixed carbon and .3 volatile matter. About three-tenths, by weight, of the coal is carbureted-hydrogen gas, which, as seen in Table VI, makes the hottest fire of the fuels there given. The temperature at which this gas breaks up into its elements is rather high, however (about 1,800° F.), and if any part of the firebox is cooled below this, part of the gases will pass away unburned, causing a great waste of heat.

109. Fresh coal, when thrown on the fire, absorbs heat, which raises its temperature and drives off the hydrogen and a portion of the carbon, combined in various chemical unions known as hydrocarbons, of which methane, or carbureted hydrogen, is one. Before burning takes place, this preparatory process of decomposition always occurs, and the products then burn in a certain regular order; the gases burn first, combining with the oxygen of the air to form water and carbon dioxide, while the coke burns last, combining with oxygen to form carbon dioxide.

110. Quantity of Air Required.—For every pound of coal burned in a firebox, enough air must be supplied to furnish sufficient oxygen for the complete combustion of .3 pound of carbureted-hydrogen gas, and .55 pound of carbon. Since, according to Table IV, 152 cubic feet of air is necessary to supply sufficient oxygen to completely burn 1 pound of carbon, it will be seen that $.55 \times 152 = 84$ cubic feet, nearly, must be supplied in burning .55 pound. To completely burn .3 pound of carbureted hydrogen, $.3 \times 230 = 69$ cubic feet of air must be supplied. So that, to completely burn 1 pound of coal, $84 + 69 = 153$ cubic feet of air must be supplied.

This is the theoretical quantity of air required, and it is calculated on the assumption that the air is so intimately mixed with the carbon and gases of the fuel that all its oxygen combines with the fuel. Practical experience, however, teaches us that the air does not mix very thoroughly with the combustible parts of the coal in the firebox, some of it passing through the tubes and up the stack, without having an opportunity to part with its oxygen. If, therefore, only the theoretical amount of air were admitted to the firebox, it would not supply sufficient oxygen to completely burn the coal, and thus heat would be wasted.

Practical experience in locomotive work, in fact, seems to indicate that about 250 cubic feet (nearly 19 pounds) of air per pound of coal is necessary to secure complete combustion when admitted in the proper manner.

111. If too much air is admitted to the firebox, it wastes heat in two ways: (1) The extra air is heated in the firebox and carries a great deal of heat with it as it escapes through the stack at a high temperature. (2) In order that this increased volume of gases and air may pass through the tubes in a given time, they must acquire a greater velocity, and consequently they will have less time in which to impart their heat to the water.

The effect of admitting too much air to the firebox can very readily be seen by opening the fire-door, for the large volume of cool air thus allowed to pass into the firebox absorbs and carries away so much heat that the steam pressure begins to drop almost at once. The same effect is noticed when holes are allowed to form in the fire.

112. It is impossible to so regulate the thickness of the fire as to allow sufficient air to be admitted through the grates to burn both the coke and also the volatile gases of the coal. The greatest quantity of air is required just after a charge of coal is put in, and, if the fire is sufficiently thin to supply the necessary air at that time, it will supply too much as soon as the gases have been burned. Then, again, as regards facilitating the air supply, the fire would require to be thinnest when the engine was making its greatest effort, and, at such times, the exhaust would be most violent and would tear holes in the fire, through which large quantities of cold air would flow, and so reduce the temperature of the firebox, besides carrying small pieces of unburned coal into the tubes, thus causing a still further waste.

113. Consumption of Gaseous Products.—It has already been seen that 100 pounds of average bituminous coal produces, in coking, about 55 pounds of solid carbon and 30 pounds of volatile gases. To secure the combustion of the coke or carbon only, would be a comparatively simple matter; it is in the thorough burning of the gases that the chief difficulty is experienced. To burn the gases completely it is necessary: (1) to maintain them at the igniting temperature while in the firebox; (2) to admit sufficient air for their complete combustion; and (3) to admit this air in as small streams as practicable, so that the air and the gases may mix as quickly and completely as possible while in the firebox and at the igniting temperature.

114. The coke can take its own time for burning, as it remains on the grates until consumed. The gases, on the other hand, begin their flight to the tubes the moment they are distilled; they have, consequently, but a fraction of a second in which to mix with the air and burn before they reach the tubes. Time, therefore, has a very important influence on the combustion of the gases, and if they do not have sufficient time to mix completely with the air while in the firebox, and at an igniting temperature, they pass off unconsumed, as no combustion takes place within the tubes. This is why a brick arch aids combustion.

115. Air for the combustion of the gases should not be admitted in large streams, as, for instance, when the fire-door is opened, for in that case it forms a distinct current of cold air that does not mix with the gases but cools them below the igniting temperature, and they pass off unburned. When admitted in small streams, the air is heated quickly and becomes more thoroughly mixed with the gases, and complete combustion is then more nearly secured. The volume of gases is greatest just after coal is put in; the greatest volume of air, therefore, should be supplied at that time, and the supply diminished as the volume of gases generated diminishes.

116. Temperature in Firebox.—The temperature in the firebox must be at about 1,800° F. before the gases will separate into their elements and burn. The maximum temperature attained in the firebox of a locomotive is from 2,000° to 2,500° F., therefore, the difference between the igniting temperature of the gases and the maximum temperature in the firebox is so small, comparatively, that constant care must be exercised to prevent the temperature from falling below 1,800° F. It becomes necessary, therefore, to judge of the temperature in the firebox by the appearance of the fire, for if the temperature is known, the conditions of combustion may be inferred. The appearance of the fire at different temperatures is given in Table VII.

TABLE VII

TEMPERATURES INDICATED BY COLOR OF FIRE

Temperature Degrees Fahrenheit	Appearance	Temperature Degrees Fahrenheit	Appearance
980	Red—just visible	2,010	Dull orange
1,290	Dull red	2,190	Bright orange
1,470	Dull cherry red	2,370	White heat
1,657	Full cherry red	2,550	White welding heat
1,830	Bright red	2,740	Dazzling white heat

117. The theoretical temperature of combustion of average bituminous coal was given in Table VI as 4,080° F. As just stated, the temperature attained by the combustion of bituminous coal in the firebox of a locomotive is from 2,000° to 2,500° F.; this difference between theoretical and actual temperatures is due to the losses of heat that take place during combustion in the firebox. These losses are as follows: (1) Heat is lost by some of the gases escaping unburned, and by small pieces of coal dropping through the grates or being drawn through the tubes unconsumed; (2) more air is usually supplied than is required for combustion, and, as this superfluous air and the resultant gases of combustion pass out through the stack, they carry off heat, which reduces the temperature in the firebox; (3) there are losses due to radiation and convection of heat from the boiler; and (4) there is the absorption of heat by the water in the boiler.

The heat absorbed by the water is the chief factor in the reduction of the temperature, and it is due principally to this loss that a higher temperature is not obtained.

SMOKE

FORMATION OF SMOKE

118. Smoke, such as is seen issuing from a chimney or from the smokestack of a locomotive, consists simply of water vapor and the gaseous products of combustion, colored with fine particles of carbon; the blacker the smoke, the more carbon is present as coloring matter.

The formation of smoke takes place as follows: When a quantity of fresh bituminous coal is thrown into the firebox, it absorbs heat so rapidly that the temperature there is reduced below that of ignition of the gases, which, as they are driven off from the coal, appear as a dark-yellow or brownish-colored vapor. This vapor is not the same as that which issues from the smokestack, called smoke, but is carbureted-hydrogen gas, colored by tarry matter, sulphur, and other volatile ingredients.

119. When the carbureted hydrogen attains the proper temperature, it ignites and burns as a flame. The hydrogen unites with oxygen and passes off as water vapor, or steam; the carbon liberated is partly consumed, and partly passes away unconsumed as small particles of solid carbon, called **soot.** It is this latter that colors the escaping gases of combustion and forms what is called smoke.

Had sufficient oxygen been present and in contact with the carbon while its temperature was high enough for them to combine, all the carbon would have been burned and the formation of smoke prevented. Smoke once formed is incombustible at firebox temperatures, as the carbon, or soot, will burn only at a very high temperature.

120. Smoke may be formed, even at high temperatures, if there is not sufficient oxygen present to combine with the carbon as it is liberated; or it may form, when sufficient oxygen is present, if the temperature of the flame is cooled below the igniting temperature of the carbon before the oxygen comes into contact with it. The formation of smoke, due to an insufficient supply of air, may be shown by placing a chimney over a lamp flame and then closing either end. The function of a lamp chimney is to produce an upward draft of air, which is deflected against the flame and furnishes a supply of oxygen sufficient to consume all the carbon while it is at a white heat in the flame. If either end of the chimney is wholly or partly stopped up, the flame will at once begin to smoke, because there is not sufficient oxygen coming in contact with it to burn all the carbon, which therefore passes off as soot or lampblack. As soon as the obstruction is taken from the end of the chimney, however, the current of air through it is resumed, and the smoke ceases.

An example of cooling the flame of a gas below the igniting temperature of the carbon, thereby causing it to smoke when an abundant supply of oxygen is at hand, may be furnished by placing a pan of cold water above the flame. The water will absorb heat from the flame so rapidly that the temperature of the flame will be reduced below the igniting temperature of the carbon, which will consequently pass off unconsumed as soot.

PREVENTION OF SMOKE

121. Carbon, in a gaseous state, before it is liberated from the hydrocarbon gases of the coal, is invisible; but if, after the hydrocarbons have been broken up by the heat, the carbon is not burned, and is allowed to cool, it appears in the solid form as black soot, and forms smoke. The formation of smoke, therefore, can be largely prevented by completely burning all the carbon as it is liberated from the hydrocarbons, so that none will escape in the solid form as soot. All the carbon can be burned if sufficient oxygen is brought in contact with it as it is liberated, and at the igniting temperature. This is the proper method of preventing the formation of smoke, and it will be found very efficient if the coal is fired in small quantities. For instance, if only small charges of coal are fired at a time, and at regular intervals, smoke will be almost entirely prevented.

A good firebrick arch, properly constructed and applied, assists very materially in the prevention of smoke, because it tends to maintain the temperature at or above the igniting temperature of carbon.

It is not practicable to prevent smoke entirely at all times, as, in order to do so, an excess of air must be supplied, which may be more wasteful than if a little smoke were allowed to form.

10-9-32

HAND FIRING OF LOCOMOTIVES

EXAMINATION QUESTIONS

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(1) ✓ State in their order the several operations to be followed in preparing a fire before starting a trip.

(2) ✓ In building up a fire, why should the blower be used only when necessary?

(3) ✓ How is it possible to tell, from the appearance of a fire, where a clinker is forming?

✓ (4) Why do leaky tubes reduce the draft through the fire?

(5) ✓ What is the estimated loss in coal for every minute the pop is open?

(6) ✓ How often and when should the grates be shaken?

(7) ✓ Why is it important to carry as even a steam pressure as possible?

(8) ✓ What two elements form the principal part of coal?

(9) ✓ What is meant by fixed carbon?

(10) What elements form the volatile part of the fuel, and what is this part of the fuel usually called?

(11) What is combustion?

(12) What is meant by the igniting temperature?

(13) What three conditions are necessary before burning occurs?

(14) (*a*) Which is the more difficult to burn, the fixed carbon or gases? (*b*) Why?

(15) (*a*) What gas is formed when carbon burns in an insufficient supply of air? (*b*) In a full supply of air?

(16) Define the heat unit known as the British thermal unit.

(17) How many heat units are produced by the burning of one pound of carbon when burned to carbon dioxide, and also to carbon monoxide?

(18) In what form are iron and sulphur usually found in coal?

(19) What must be the firebox temperature before the hydrocarbons will break up and burn?

(20) (*a*) What is smoke and how is it formed? (*b*) How can it be prevented? (*c*) Why should it be prevented?

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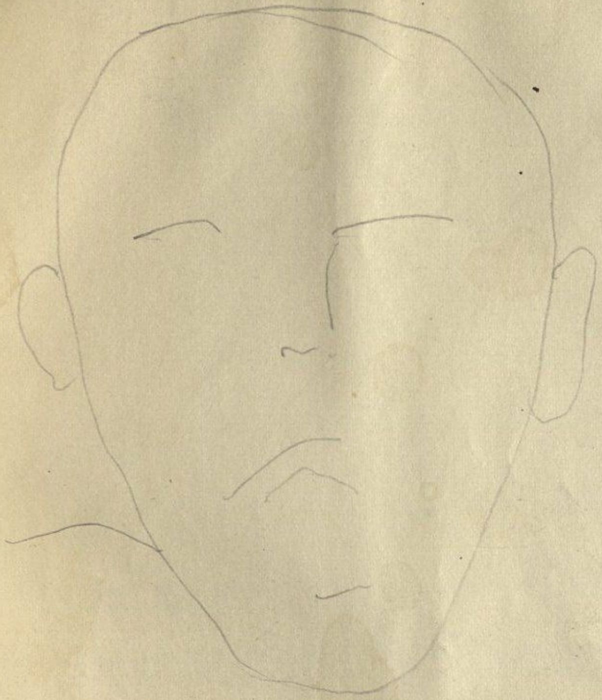

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